PB81-113045

Predicting Cattle Feedlot Runoff and Retention Basin Quality

Oregon State Univ.
Corvallis

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Nov 80

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 600/2-80-192	2.	3. RECIPIENT'S ACCESSION NO. PB81 113045
4. TITLE AND SUBTITLE PREDICTING CATTLE FEEDLOT RUNOFF AND RETENTION BASIN QUALITY		5. REPORT DATE October 1977 to September '79 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. Ronald Miner, James K. Koelliker, Marshall J. English		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Agricultural Engineering Oregon State University Corvallis, Oregon 97331		10. PROGRAM ELEMENT NO 1BB770 11. CONTRACT/GRANT NO. R805499
12. SPONSORING AGENCY NAME AND ADDRESS Robert S. Kerr Environmental Research Lab - Ada, OK Office of Research and Development U.S. Environmental Protection Agency Ada, Oklahoma 74820		13. TYPE OF REPORT AND PERIOD COVERED Final (10/1/77-9/30/79) 14. SPONSORING AGENCY CODE EPA/600/15
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

A procedure was devised to predict the quantity and quality of cattle feedlot runoff entering a runoff retention basin whenever precipitation occurs in excess of the surface holding capacity of the lot or whenever accumulated snow would melt. These predictions are based upon size and location of the feedlot, previous conditions, and daily climate data. Runoff retention basin liquid content and quality are predicted on a daily basis. The model considers inputs and outputs as well as chemical and biological changes which are occurring on a continuous basis. The quality parameters which are predicted on a daily basis include: chemical oxygen demand, total Kjeldahl nitrogen, ammonia nitrogen, total phosphorous, total solids, fixed dissolved solids, total coliforms, fecal coliforms and fecal streptococcus. A cattle feedlot in Illinois was sampled intensively to adjust the various coefficients of the predictive tool.

In order to determine quality changes between a runoff retention basin or other manure laden water storage and the receiving soil surface, a separate study was conducted. Ammonia nitrogen is the major constituent lost. A technique was devised and tested to predict ammonia nitrogen loss as a function of wastewater quality, sprinkler equipment characteristics, and current weather data. Losses range from zero to 40 percent.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Agricultural wastes Animal husbandry Waste disposal Water quality Models	Animal waste management Feedlot runoff Runoff retention basin quality Nitrogen losses	68D 98B 98C

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

PB81-113045

EPA 600/2-80-192
November 1980

PREDICTING CATTLE FEEDLOT RUNOFF AND RETENTION BASIN QUALITY

by

J. Ronald Miner
James K. Koelliker
Marshall J. English
Department of Agricultural Engineering
Oregon State University
Corvallis, Oregon 97331

Grant No. R-805499

Project Officer

R. Douglas Kreis
Source Management Branch
Robert S. Kerr Environmental Research Laboratory

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma is charged with the mission to manage research programs to investigate the nature, transport, fate, and management of pollutants in groundwater and to develop and demonstrate technologies for treating wastewaters with soils and other natural systems; for controlling pollution from irrigated crop and animal production agricultural activities; for controlling pollution from petroleum refining and petrochemical industries; and for managing pollution resulting from combinations of industrial/industrial and industrial/municipal wastewaters.

This project was initiated to develop a predictive model which would estimate the water temperatures and pollutant strength of retained storm water runoff for specific retention pond volumes. This information is useful in determining optimal periods and land area requirements for environmentally acceptable disposal of feedlot stormwater runoff to croplands and soils. The combination of these findings with results obtained from previous modeling efforts designed to determine the techniques for predicting the size of runoff retention facilities to achieve various levels of runoff controls for both specific design storms and chronic storms will provide the technology required to design total runoff control and land disposal practices.

William C Galegar

William C. Galegar, Director
Robert S. Kerr Environmental
Research Laboratory

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

ABSTRACT

Runoff from cattle feedlots and other unroofed livestock confinement areas is produced during and immediately following rainfall events and during snowmelt. Various researchers have measured the quality of this runoff, however, only limited efforts have been devoted to predicting runoff quality as a function of local climatic data and feedlot characteristics. Feedlot runoff is typically stored in an earthen runoff retention until it can be applied to cropland for disposal or for utilization as irrigation water or for its nutrient value. Should a runoff event occur which exceeds the storage capacity of the retention basin, discharge will occur. It is important to be able to predict the quality as well the quantity of feedlot runoff and retention basin contents if the wastewater is to be effectively utilized and if the pollution potential of various runoff control systems are to be evaluated.

A procedure was devised to predict the quantity and quality of cattle feedlot runoff entering a runoff retention basin whenever precipitation occurs in excess of the surface holding capacity of the lot or whenever accumulated snow would melt. These predictions are based upon size and location of the feedlot, previous conditions, and daily climate data. Runoff retention basin liquid content and quality are predicted on a daily basis. The model considers inputs and outputs as well as chemical and biological changes which are occurring on a continuous basis. The quality parameters which are predicted on a daily basis include: chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), total phosphorous (Total-P), total solids (TS), fixed dissolved solids (FDS), total coliforms (TC), fecal coliforms (FC) and fecal streptococcus (FS). A cattle feedlot in Illinois was sampled intensively to adjust the various coefficients of the predictive tool.

In order to determine quality changes between a runoff retention basin or other manure laden water storage and the receiving soil surface, a separate study was conducted. NH_3-N is the major constituent lost. A technique was devised and tested to predict NH_3-N loss as a function of wastewater quality, sprinkler equipment characteristics, and current weather data. Losses range from zero to 40 percent.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

This report was submitted in fulfillment of Grant Number R-805499 by Oregon State University under the partial sponsorship of the U.S. Environmental Protection Agency (EPA). This report covers the period from October 1, 1977 to September 30, 1979. Work was completed as of December 31, 1979.

CONTENTS

....iii
Foreword.. iv
Abstract..vii
Figures... x
Tables..xiv
Abbreviations..xvii
Acknowledgements..
.... 1
1. Introduction... 4
2. Conclusions.. 6
3. Recommendations.. 7
4. Hydrologic Model....................................... 13
5. Modeling Cattle Feedlot Runoff Quality................. 25
6. Modeling the Retention Pond Liquid Quality............. 55
7. Field Sampling Program for Data Collection............. 61
8. Incorporation of Field Data into Predictive Model...... 70
9. Demonstration of the Model.............................
10. Modeling of Ammonia Losses in Sprinkler Application ... 78
of Animal Wastes..
....123
References..
Appendices

A. Previously available cattle feedlot runoff data........126
B. Previously available cattle feedlot runoff
retention basin quality data..............................145
C. Field data from field lot..............................151
D. Field data from ammonia volatilization experiments.....165
E. Summary of quality control analysis for feedlot
runoff wastewater laboratory..............................170
F. Definition of terms and computer program for cattle
feedlot runoff retention basin quality predictions.......172
G. Definition of terms and computer program for the
ammonia loss prediction model.............................180
H. English to SI unit conversions.........................188

FIGURES

Number Page

1 Feedlot runoff generating system........................ 8

2 Liquid accounting for feedlot runoff retention basin.. 12

3 Influence of season on COD 15 cm (6 in) below the surface of Lagoon 119 receiving cattle feedlot runoff at Pratt, Kansas (Manges, et al., 1975)....... 26

4 Daily rainfall and changes in N concentrations during 1974 in a holding pond for beef (Dickey and Vanderholm, 1976)................................ 27

5 Seasonal changes in the EC and COD in a holding pond during 1974 for beef feedlot runoff (Dickey and Vanderholm, 1976)................................ 28

6 Seasonal variation of TKN in a holding pond for beef feedlot runoff during 1975 (Dickey and Vanderholm, 1976)................................... 29

7 Seasonal changes in Total-P and K concentrations in a holding pond for beef feedlot runoff during 1974 (Dickey and Vanderholm, 1976).................. 30

8 Seasonal changes in Total-P and K concentrations in a holding pond for beef feedlot runoff during 1975 (Dickey and Vanderholm, 1976).................. 31

9 Seasonal changes in Na^+ and Cl^- concentrations in a holding pond for beef feedlot runoff (Dickey and Vanderholm, 1976)....................... 32

10 Seasonal variation in the TS concentrations in a holding pond for beef feedlot runoff (Dickey and Vanderholm, 1976)................................ 33

11 COD accounting for feedlot runoff retention basin...... 35

12 N accounting for feedlot runoff retention basin........ 40

13 Relationship between partial pressure of NH_3 gas to total NH_3-N to liquid temperature in an anaerobic swine manure lagoon (data from Koelliker and Miner, 1973).......... 43

14 Relationship between Total-P and NH_3-N in a holding pond for beef. Data from Dickey and Vanderholm (1976).......... 48

15 Total-P accounting for feedlot runoff retention pond.......... 49

16 TVS and FDS accounting for feedlot runoff retention pond.......... 52

17 Layout of feedlot and runoff control system at the field site.......... 56

18 Stage-volume and stage-surface area relationships for runoff retention pond at field site.......... 58

19 Measured and model predicted COD concentrations in a cattle feedlot runoff retention basin.......... 64

20 Measured and model predicted NH_3-N concentrations in a cattle feedlot runoff retention basin.......... 65

21 Measured and model predicted Org-N concentrations in a cattle feedlot runoff retention basin.......... 66

22 Measured and model predicted Total-P concentrations in a cattle feedlot runoff retention basin.......... 67

23 Measured and model predicted FC numbers per 100 ml in a cattle feedlot runoff retention basin.......... 68

24 Measured and model predicted FS numbers per 100 ml in a cattle feedlot runoff retention basin.......... 69

25 Retention basin volume during a hypothetical year...... 73

26 Retention basin COD concentration during a hypothetical year.......... 74

27 Retention basin NH_3-N and Org-N concentrations during a hypothetical year.......... 75

28 Retention basin Total-P concentration during a hypothetical year.......... 76

29 Retention basin TC and FS organism concentration during a hypothetical year. FC were half the TC..... 77

30 Losses of NH_3-N from fertilizer salts in relation to NH_3-N concentration in the irrigation water (Henderson, et al., 1955)............................ 79

31 A resistance model of evaporation during sprinkling (Seginer, 1971).. 83

32 Concentration gradients between two contacting phases (Welty, et al., 1976)........................ 86

33 Drag coefficient for a sphere (Sprinkler Irrigation Association, 1975)................................ 92

34 Diagram of particle dynamics (Smith, 1970)............. 93

35 General flowchart of the programmed model.............101

36 Filter design..103

37 Schematic of swine center with waste disposal system and test plot shown..........................104

38 Grid of collectors.....................................106

39 Collector design.......................................107

40 Predicted variation of NH_3-N loss with temperature and pH..110

41 Predicted NH_3-N loss in far spray: variation with pH...111

42 Predicted relationship of NH_3-N loss to nozzle height at pH of 9.....................................113

43 Droplet trajectory as predicted by colputer model (average droplet)....................................114

44 Predicted variation of NH_3-N loss with distance travelled from nozzle (average droplet)..............114

45 NH_3-N loss in short-distance, small droplets ("near" spray)...116

46 NH_3-N loss in long-distance, large droplets ("far" spray)..117

TABLES

Number Page

1 Cattle Feedlot Runoff Retention Basin Quality Parameters to be Predicted in the Developed Model........ 3

2 Inputs to the Hydrologic Model........ 9

3 Factors Identified to Have an Influence on the Quality of Cattle Feedlot Runoff........ 14

4 Form of Lot Moisture Calculations........ 20

5 Model Coefficients........ 62

6 Average Monthly Air Temperatures Assumed to Demonstrate the Feedlot Runoff and Retention Basin Quality Predictive Model........ 70

7 Predicted Cattle Feedlot Runoff COD, TKN, NH_3-N, and P Under Various Conditions........ 71

8 Predicted Concentration of Indicator Microorganisms in Cattle Feedlot Runoff........ 72

9 Variation of Relative Humidity with Temperature During Study........112

10 Average Percent Change in Waste Parameters During Sprinkling........119

11 TC Changes During Spraying: Raw Data........121

12 NH_3-N Loss With Herbage........122

A-1 BOD_5 Concentrations in Runoff From a Dirt Experimental Cattle Feedlot in Kansas During Various Seasons of 1965. (Miner, 1967)........126

A-2 NH_3-N Concentrations in Runoff From a Concrete and a Dirt Experimental Cattle Feedlot in Kansas. (Miner, 1967)........127

A-3 NO_3-N Concentrations in Runoff From a Concrete and a Dirt Cattle Feedlot in Kansas During Two Seasons of 1965. (Miner, 1967)........................127

A-4 TSS Concentrations in Runoff From a Concrete and a Dirt Experimental Cattle Feedlot in Kansas in 1965. (Miner, 1967)..............................128

A-5 NO_2-N Concentrations in Runoff From a Concrete and a Dirt Experimental Cattle Feedlot in Kansas during Two Seasons of 1965. (Miner, 1967)....128

A-6 Densities of TC, FC, and FS in Runoff From a Concrete Experimental Cattle Feedlot in Kansas During July Through November 1965. (Miner, 1967)....129

A-7 Densities of TC, FC, and FS in Runoff From a Dirt Experimental Cattle Feedlot in Kansas During July Through November 1965. (Miner, 1967)....129

A-8 BOD_5 Concentrations in Runoff From a Concrete Experimental Cattle Feedlot in Kansas During Various Seasons of 1965. (Miner, 1967)..............130

A-9 Cattle Feedlot Runoff Characteristics. (Loehr, 1974)...131

A-10 Concentrations of Pollutants in Runoff From a Concrete Surfaced Lot Near Lubbock, Texas on Which Cattle Were Fed Roughage-Concentrate Ration. (Wells, et al., 1972)........................132

A-11 Concentrations of Pollutants in Runoff From a Concrete Feedlot Near Lubbock, Texas Resulting From a 3.6 cm (1.4 in) Rainfall Starting at 11:00 p.m. on August 24, 1969. (Texas Tech. University, 1971)....................................132

A-12 Concentrations of Pollutants in Runoff From a Concrete Surfaced Feedlot Near Lubbock, Texas on Which Cattle Were Fed An All Concentrate Ration. (Texas Tech. University, 1971)..............133

A-13 Average Concentrations of Pollutants in Runoff From a Dirt Lot Near Lubbock, Texas on Which Cattle Were Fed Roughage-Concentrate Ration. (Texas Tech. University, 1971)........................133

A-14 Concentrations of Pollutants in Runoff from a Dirt Lot Near Lubbock, Texas Resulting From Precipitation Starting at 11:00 p.m. on August 24, 1969. (Texas Tech. University, 1971).....134

TYPING GUIDE SHEET

A-15 Average Concentrations of Pollutants in Runoff From a Dirt Lot Near Lubbock, Texas on Which Cattle Were Fed an All-Concentrate Ration. (Texas Tech. University, 1971) 134

A-16 Quality of Runoff From Steep Non-Paved Cattle Feedlots (Hamilton Standard, 1973) 135

A-17 Quality of Runoff From Non-Paved Cattle Feedlots. (Hamilton Standard, 1973) 136

A-18 Quality of Runoff From Paved Cattle Feedlots. (Hamilton Standard, 1973) 137

A-19 Runoff Quality From a 0.4 ha (1 ac) Paved Cattle Feedlot in East-Central Illinois Collected November 4, 1974 Following a 1.25 cm (0.5 in) rainfall 138

A-20 Concentrations of Selected Ions in Runoff From Beef Cattle Feedyards. (Clark, et al., 1975) 139

A-21 Average Chemical Characteristics of Runoff From Beef Cattle Feedyards. (Clark, et al., 1975) 139

A-22 General Information For Each Beef Cattle Feedyard From Which Data Were Reported in Tables A-20 and 21 140

A-23 Summary of Information and Average Runoff Quality From Eight Great Plains Beef Feedlots. (Clark, et al., 1975) 141

B-1 BOD and COD Concentrations of a Beef Feedlot Runoff Retention Near Mead, Nebraska. (Gilbertson, et al., 1971) 145

B-2 Nutrient Content of East-Central Illinois Holding Pond Water Applied to Cropland. (Dickey and Vanderholm, 1976) 146

B-3 Analyses of Manure Solids, Settling Pond Solids, and Holding Pond Sediment, East-Central Illinois Cattle Feedlot. (Dickey and Vanderholm, 1976) 146

B-4 Average Fraction of TS in Holding Pond Water That Were Suspended Samples, Collected From Three Illinois Cattle Feedlots During 1974 and 1975. (Dickey and Vanderholm, 1976) 147

PAGE NUMBER
EPA-287 (Cin.)
(8-78)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6 1/2"

B-5 Average Fraction of TKN in Holding Pond Water Present in NH_3-N Form. Samples Collected From Three Concrete Surfaced Cattle Feedlot Waste Management Systems. (Dickey and Vanderholm, 1976) 147

B-6 Beef Feedlot Runoff Holding Pond Composition. Concrete Surfaced Lot in Northeast Illinois. (Dickey and Vanderholm, 1975) 148

B-7 Beef Feedlot Runoff Holding Pond Composition. Concrete Surfaced Lot in Northwest Illinois. (Dickey and Vanderholm, 1976) 148

B-8 Beef Feedlot Runoff Holding Pond Composition. Concrete Surfaced Lot in East-Central Illinois. (Dickey and Vanderholm, 1976) Significant Rainfall in Early May, Mid-June, Mid-August, and Early September 149

C-1 Record of Rainfall and Volume of Stored Waste Pumped Into and Out of the Retention Basin at the Field Site 151

C-2 Runoff Retention Basin Temperature, pH and Staff Gauge Height Measured at the Field Site Between May and November 1978 153

C-3 Runoff Retention Basin COD, NH_3-N, TKN, Org-N and Total-P Concentrations in Samples Collected at the Field Site Between May and November 1978......158

C-4 Runoff Retention Basin Solids Concentrations in Samples Collected at the Field Site Between May and November 1978 161

C-5 Runoff Retention Basin Indicator Microorganism Concentrations in Samples Collected at the Field Site Between May and November 1978 164

D-1 Temperature and Constituent Concentrations Measured During NH_3-N Volatilization Experiments 165

E-1 Summary of Quality Control Analyses for Feedlot Runoff Wastewater Laboratory May 8 to July 6, 1978...170

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

LIST OF ABBREVIATIONS AND SYMBOLS USED IN THE TEXT

ABBREVIATIONS

BOD --biochemical oxygen demand
BOD_5 --five day biochemical oxygen demand
Ca --calcium ion
Cl^- --chloride ion
COD --chemical oxygen demand
EC --electrical conductivity
FC --fecal coliforms
FDS --fixed dissolved solids
FS --fecal streptococci
ha --hectare
Inorg-P --inorganic phosphorous
K --potassium
Mg^{++} --magnesium ion
MPN --most probable number
N --nitrogen
Na^+ --sodium ion
NH_3-N --ammonia nitrogen
NH_4^+ --ammonium ion
NO_3-N --nitrate nitrogen
NO_2-N --nitrite nitrogen
Org-N --organic nitrogen
Org-P --organic phosphorous
P --phosphorous
PO_4-P --ortho phosphate
TC --total coliforms
TDS --total dissolved solids
Total-P --total phosphorous
Total Alk. --total alkalinity
TKN --total Kjeldahl nitrogen
TS --total solids
TSS --total suspended solids
TVS --total volatile solids
VDS --volatile dissolved solids
VSS --volatile suspended solids

LIST OF ABBREVIATIONS USED IN THE COMPUTER MODEL DEVELOPMENT

CCOD	--COD concentration in feedlot runoff, mg/ℓ
DISVOL	--volume of liquid removed by disposal operations, m^3 per ha of feedlot surface
DSCHRG	--volume of liquid discharged by uncontrolled events, m^3 per ha of feedlot surface
FCOLI	--fecal coliform concentration, number per 100 ml
FDS	--fixed dissolved solids concentration, mg/ℓ
FNH3	--fraction of total nitrogen concentration present as ammonia
FSTRF	--fecal streptococcus concentration, number per 100 ml
KC_{PT}	--rate coefficient for COD degradation, day^{-1}
K_I	--rainfall intensity factor
K_L	--feedlot surface material factor
KL_{20}	--temperature coefficient for COD liquefaction
KL_{PT}	--COD liquefication factor
K_M	--feedlot moisture factor
K_P	--source of runoff factor
K_{SA}	--salt accumulation factor
K_T	--temperature factor
K_{TB}	--temperature correction factor for bacteria in runoff
LCODD	--degradable COD in the basin, kg/ha of feedlot
LCODN	--nondegradable COD in the basin, kg/ha of feedlot
LCODT	--total COD in liquid, kg/ha of feedlot
LM	--feedlot moisture, mm
LMHC	--feedlot moisture holding capacity, mm
NH_3	--ammonia nitrogen concentration
NTOT	--total nitrogen concentration, mg/ℓ
P	--phosphorous concentration, mg/ℓ
PCOD	--COD concentration in retention basin liquid, mg/ℓ
PETBS	--potential evaporation from a liquid surface, mm
PF	--fraction of potential liquid surface evaporation which actually occurs
PONVOL	--liquid volume in the retention basin, m^3 per ha of feedlot surface
PRECIP	--precipitation onto the basin surface, m^3 per ha of feedlot surface

PT --retention basin liquid temperature, $^\circ$C

r --correlation coefficient

RCOD --COD in feedlot runoff, kg/ha of feedlot

RUNOFF --feedlot runoff into the basin, m^3 per ha of feedlot surface

SCODL --liquefiable COD in the settled solids, kg/ha of feedlot

SCODN --nonliquefiable COD in the settled solids, kg/ha of feedlot

SEVAP --evaporation from the basin surface, m^3 per ha of feedlot surface

SLUDGE --volume of solids accumulated on retention basin bottom, m^3/ha of feedlot

T --temperature, $^\circ$C

TCOLI --total coliform concentration, number per 100 ml

T_N --temperature N days ago

Ts --feedlot surface temperature, $^\circ$C

TS --total solids concentration, mg/ℓ

TVS --total volatile solids concentration, mg/ℓ

T_1 --average air temperature one day ago, $^\circ$C

ΔV --daily change in retention basin liquid volume, m^3 per ha of feedlot surface

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

ACKNOWLEDGMENTS

The preparation of this report was supported in part by Grant Number R-805499, U.S. Environmental Protection Agency. The cooperation of R. Douglas Kreis, Project Officer, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is gratefully acknowledged.

Field data reported in this document which were used to calibrate and adjust the retention basin quality model coefficients were based upon analysis of samples collected from the runoff retention basin of the Vernon Veatch farm near Roberts, Illinois. The cooperation of the Veatch family in sample collection and shipping and in careful field observations was instrumental in the success of this program. Dale H. Vanderholm, Department of Agricultural Engineering, University of Illinois provided local supervision of the sampling program and made a valuable input in that aspect of the program. Retention basin samples for microbiological analysis were sent to Arro Laboratories located in Jolliet, Illinois. Samples for chemical analysis were shipped to the Oregon State University Agricultural Engineering Department where they were analyzed by Camilla D. Mallonee and Sherry L. Bravinder.

Computer programming and electronic data processing were done by E. Stuart Baker. Jonathan W. Pote served as a graduate research assistant responsible for experiments on the NH_3-N loss during sprinkler application. Additional inputs instrumental to the success of the project were provided by Dr. Ted L. Willrich, Pete Lyngstrand, Rick Dieker, Mary Connors, and Miriam Schaup.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 1

INTRODUCTION

Runoff from cattle feedlots was recognized as a potential water pollutant following a series of fish-kills in Kansas in 1962. In response to those initial events, as well as subsequent experience, a technology for the control of feedlot runoff as well as a variety of regulatory schemes have evolved. The basic strategy that has proven most feasible for protection of receiving waters has been to collect stormwater runoff in a suitably designed retention basin or pond and following the storm to apply the manure ladden water to cropland in such a manner as to avoid runoff. This approach recaptures a portion of the plant nutrients thereby recovering a portion of the cost by replacing chemical fertilizers.

The runoff retention basin capacity needed at a particular location is a function of local climate, feedlot size, liquid removal equipment available, desired frequency of pumping and the desired level of pollution control. A runoff retention basin designed to retain all runoff during the most extreme weather conditions possible becomes unreasonably expensive to construct, and provides only minimal additional pollution control over a less expensive system for which well defined limitations exist. Hence, it may be concluded that a well designed feedlot runoff control system will discharge during extreme weather. Feedlot pollution control guidelines define the conditions under which discharge will occur. These are typically the ten year 24 hour storm or the 25 year 24 hour storm.

Cattle feedlot runoff is typically described as a high strength organic wastewater containing large numbers of enteric microorganisms. The quality of the runoff is highly variable depending upon such parameters as rainfall rate, temperature and feedlot surface conditions. This quality is modified by the runoff control system. As the runoff is stored in the retention structure further quality changes occur. Organic matter is stabilized, solids settle, ammonia volatilizes and enteric bacteria die off. These changes influence the quality of the basin contents and the rate of these changes is conversely influenced by the quality liquid in the basin. Hence the complexity of the system.

For various reasons, it is desirable to be able to predict the quality of the runoff retention basin contents. If runoff is to occur, the quantity and quality of the discharged material must be known to predict the impact on the receiving stream. When basin contents are to be applied to cropland, optimal application rates are a function of the nitrogen (N) concentration. Particularly, if the nutritive value of the contents is to be utilized, quality predictions are critical.

Previous modeling efforts have provided techniques for predicting the size of runoff retention facilities to achieve various levels of runoff control or to predict the runoff retention achieved by various combinations of retention basin sizes and management strategies. No previous efforts have attempted to predict the quality of retention basin contents.

The initial plan for this effort was in two phases. The first phase was to develop a predictive model which would estimate the pond volume, liquid temperature, and liquid constituent concentrations listed in Table 1. Simultaneously, a cattle feedlot runoff retention basin was to be sampled intensively to generate data for calibrating the model. In Phase II of the project, the model was to be verified by the collection of data in an intensive field study. Due to changing research priorities within the EPA, only Phase I of the project was funded. Hence, it is the purpose of this report to present the development of a continuous water quality model which will predict, on a daily basis, the quality of feedlot runoff entering a runoff retention basin and contained in the basin. That quality in the basin is the one that would be discharged in case of an uncontrolled event or removed for subsequent treatment or disposal on land. The quality predicted for a basin contents will be compared with analytical data based upon sampling a cattle feedlot runoff retention basin in eastern Illinois during the summer of 1978.

In a separate but related effort, quality changes occuring during the sprinkler application of anaerobically stored liquid manure to cropland was investigated. Those data are also included in this report.

TABLE 1. CATTLE FEEDLOT RUNOFF RETENTION BASIN QUALITY PARAMETERS TO BE PREDICTED IN THE DEVELOPED MODEL

Parameter	Abbreviation	Unit
Chemical oxygen demand	COD	mg/ℓ
Total Kjeldahl nitrogen	TKN	mg/ℓ
Ammonia nitrogen $(NH_3+NH_4^+)$-N	NH_3-N	mg/ℓ
Total phosphorous	Total-P	mg/ℓ
Total volatile solids	TVS	mg/ℓ
Fixed dissolved solids	FDS	mg/ℓ
Total solids	TS	mg/ℓ
Total coliforms	TC	No./100 ml
Fecal coliforms	FC	No./100 ml
Fecal streptococcus	FS	No./100 ml

SECTION 2

CONCLUSIONS

This project was originally proposed to include two additional years of feedlot runoff and runoff retention basin sampling at several locations to confirm the validity of the model and to better define variations in the derived coefficients as a function of site specific variables. Due to changes in priorities within the EPA, funding was not provided beyond the initial phase. Hence, there remains a degree of uncertainty concerning the degree of accuracy of the coefficients reported in this study when applied to sites in different climatic and geographic regions.

A technique was developed to predict the quality of cattle feedlot runoff based upon the various parameters previously documented to influence this phenomenon. Using this technique, it is possible to obtain a better estimate of this quality than by any other procedure currently available. Previous work by the authors of this report and others have provided a satisfactory method of estimating runoff quantity in response to climatic data and feedlot characteristics.

The runoff retention basin water quality model developed during the course of this project is based upon an analysis of all previous data that have been published on this topic and upon intensive sampling of a cattle feedlot in Illinois. As such, it represents the best technique currently available to predict the quality of runoff water available for land application under any specific climatic condition or which would be discharged should runoff occur which exceeds the storage capacity of the retention basin. Using this technique it is possible to calculate the retention basin liquid volume and the following water quality parameters on a daily basis: COD, TS, FDS, TC, FC and FS.

An analysis of water quality changes between a storage reservoir and the land surface during the process of sprinkler irrigation was made which documented that NH_3-N volatilization was the only significant change. NH_3-N volatilization can range from nearly zero to over 40 percent depending primarily on pH of the wastewater. Other variables which influence NH_3-N loss are air temperature, wind velocity, relative humidity, droplet size and travel distance of the droplet. The predictive technique devised is consistent with previous data and allows precise definition of this nutrient loss.

The results of this study can be used by livestock producers, system designers and by regulatory and planning agencies to generate the best available information. The major weakness of the information is that an inadequate quantity of confirming data were collected.

SECTION 3

RECOMMENDATIONS

A technique for predicting cattle feedlot runoff quality and feedlot runoff retention basin quality may be used to evaluate the environmental impact of cattle feedlots under a variety of climatic conditions or the quality of effluent applied to cropland may be calculated. In order to improve the confidence with which these calculations can be used, the verification and calibration portions of the project as originally proposed should be conducted.

SECTION 4

HYDROLOGIC MODEL

The objective of this project is to develop a continuous water quality model that will predict, on a daily basis, the quality of feedlot runoff: 1) entering the retention basin after running off a feedlot surface and passing through a solids trapping device either a settling basin, porous dam or grassed waterway, 2) contained in the retention basin, 3) discharged from the retention basin by uncontrolled events, 4) removed for subsequent treatment on land, and 5) deposited on the interception surface of the land treatment area. In order to achieve this objective, a hydrologic model and management scheme must be specified which will provide the input quantities which determine the length of time material has been in the basin and hence, the extent of its degradation.

This water quality model will be a complement to the quantity models that have previously been completed under EPA grants to Oregon State University and Kansas State University. The intent is, when completed, this water quality model will provide a complete quality and quantity model for cattle feedlot runoff control systems. Such a model should provide a tool for evaluating the impact of a cattle feedlot upon the water quality in a basin.

The continuous watershed model for the hydrologic portion of the feedlot runoff control system has previously been described by Zovne and Koelliker (1979). The reader is directed to that publication for a complete description of the model. Included herein will be an abridged description. Figure 1 shows a process schematic of the feedlot runoff model. The three components of the model are the feedlot runoff generating surface, a runoff retention basin and a soil moisture budget model for the runoff disposal area.

For the purposes of the hydrologic model, the surface area of the feedlot must be defined so that the depth of runoff produced times the area of the feedlot will yield the runoff volume. Likewise, the total surface area of the retention pond at maximum depth must be defined since the amount of precipitation falling upon this surface is all added to the volume of the basin. The volume of precipitation added to the basin is then the daily

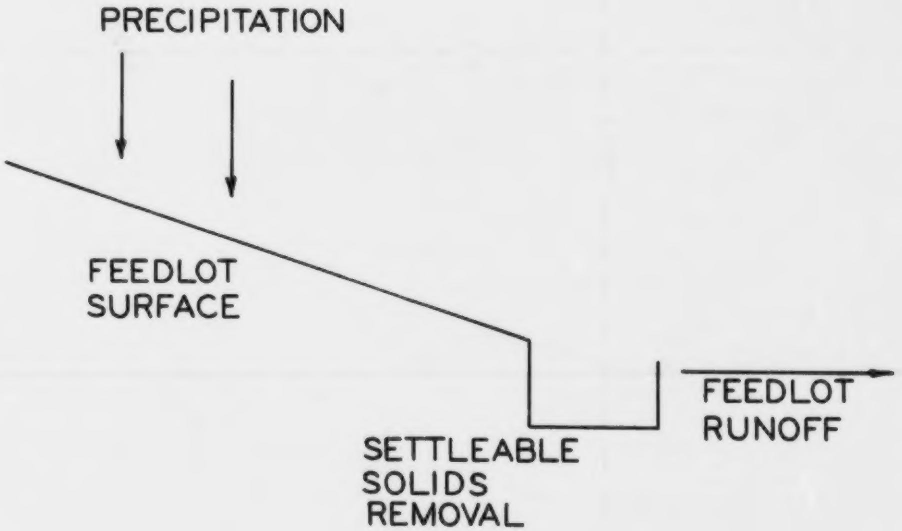
PRECIPITATION
FEEDLOT SURFACE
SETTLEABLE SOLIDS REMOVAL
FEEDLOT RUNOFF

Figure 1. Feedlot runoff generating system.

depth of precipitation times the maximum surface area. To determine evaporation from the pond, the side slope, length and width of a pond must be defined. Evaporation, considered to occur only from the actual surface area of the liquid within the pond, is equal to the actual surface area times the predicted daily depth of pond evaporation. The volume removed for disposal is a function of the area of the disposal field to which liquid can be applied by the disposal system times the depth of liquid that will be applied in one day. Therefore, the physical capabilities of the disposal system must be defined in order to set the daily disposal volume. Discharge occurs when the retention pond volume is exceeded. Therefore, a maximum pond depth is also required.

The deterministic water budget model for the hydrology of the system is driven by daily values of minimum and maximum air temperature and daily precipitation from a continuous weather record for a particular station. Other meteorological inputs required are monthly mean values of air temperature, solar radiation, relative humidity, wind travel, percent sunshine, and A and B coefficients for the Brunt equation. Other input data needed for the feedlot include a soil type in the disposal area of only 12 classifications; crop to be grown on the disposal area; the management system for operation of disposal, if any; and the limitations of the amount of runoff applied in any one period, if any. These inputs are summarized in Table 2.

TABLE 2. INPUTS TO THE HYDROLOGIC MODEL

Inputs
Physical characteristics of the system
Feedlot surface area
Surface area of retention basin at capacity
Retention basin dimensions and interior slopes
Disposal field
Area
Soil type (one of 12)
Crop to be grown
Management system
Maximum application rate
Climatic data
Monthly mean data
Air temperature
Solar radiation
Relative humidity
Wind travel
Percent sunshine
Brunt equation coefficients A and B

(continued)

TABLE 2 (continued)

Inputs
Daily values
Maximum temperature
Minimum temperature
Precipitation

This model was developed as a technique to evaluate a particular feedlot in a particular location within the continental United States. As such, it is considered to be the most rigorous hydrologic model that has been yet developed for the feedlot runoff control system situation. All masses of constituents will be reported in kg/ha and all concentrations in mg/ℓ.

ADAPTATION TO HYDROLOGIC MODEL FOR WATER QUALITY CONSIDERATIONS

For purposes of the water quality model, a unit feedlot area is considered. To accommodate this approach with the hydrologic model, a runoff control system that provides realistic runoff control at a particular location was first determined. Then, all volumes that were generated in the hydrologic model are divided by the feedlot area to provide values in terms of a depth per unit area of feedlot. Further, all depths are converted to SI units of cubic meters per hectare (m^3/ha). This approach allows for a simpler look at the quality of runoff without complicating the issue with the physical sizes of the feedlot runoff control system. This postulates that the size of the feedlot has no influence upon the quality of the runoff water. Although the shape of pond, depth of pond, etc., may have some influence on the water quality within the system at any particular time. The ability of a model to predict feedlot runoff control quality is unlikely to be sufficiently precise to separate such variables.

For the water quality model, the daily change in liquid volume in the retention basin in m^3/ha, then is described by

$$\Delta V = RUNOFF + PRECIP - SEVAP - DISVOL - DSCHRG \quad (1)$$

where,

ΔV = change in liquid volume

RUNOFF = feedlot runoff into the basin

PRECIP = precipitation onto the basin surface

SEVAP = evaporation from basin surface

DISVOL = amount of liquid removed by disposal operation

DSCHARG = amount of liquid discharged by uncontolled events

Figure 2 shows a sketch of the operation of the water budget for the retention pond for the water quality model. Infiltration through the bottom of the pond is assumed to be zero. Sludge is the volume of solids that will accumulate within the retention pond as estimated in the COD portion of the model as discussed later.

The volume of liquid within the pond at any time per ha of feedlot, PONVOL, will be equal to the pond volume (PONVOL) yesterday plus ΔV minus the increased volume occupied by the sludge.

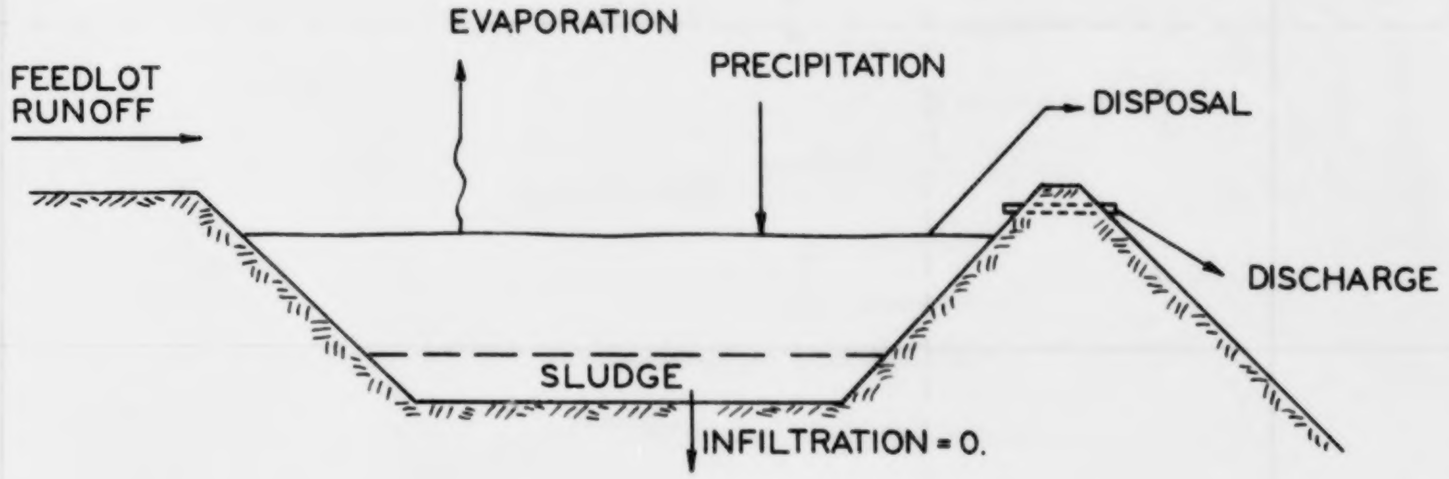
EVAPORATION
FEEDLOT RUNOFF
PRECIPITATION
DISPOSAL
DISCHARGE
SLUDGE
INFILTRATION = 0.

Figure 2. Liquid accounting for feedlot runoff retention basin.

SECTION 5

MODELING CATTLE FEEDLOT RUNOFF QUALITY

The cattle feedlot runoff process is a complex phenomenon controlled by a variety of physical, climatological, and environmental factors. In order for a modeling effort to be effective, however, these factors need to be selectively handled so the end product is useful as a planning tool even where in-depth local data may not be available. Table 3 lists the factors that have been identified as being of overall importance in predicting runoff quality.

Although a fully satisfactory relationship between the factors influencing the cattle feedlot runoff process and runoff quality has not been achieved nor is it likely to be achieved in the future, there are sufficient data available to allow runoff quality to be used as an input in calculating the quality of runoff retention basin contents. The structure of this process will utilize commonly available climatic and physical data to make the needed estimates. The following basic structure is inherent in the process being proposed.

1. Cattle feedlot runoff is an area based phenomenon; hence, the constituent concentrations are independent of feedlot size.

2. Being an area based process, the number of cattle on the lot is not an input to the process. This assumes the cattle are present in sufficient intensity to preclude the growth of vegetation, but not at such an intensity to inhibit efficient animal growth nor to result in unsuitable lot conditions. Typically this translates into an animal density of between 350 and 850 head per ha (150 and 350 head/ac).

3. Since some technique to remove easily settleable solids from runoff, prior to its introduction into a retention basin is sound design, such a function is assumed to be in place as part of this model. Such a device might be a debris basin, grassed waterway, sedimentation basin, porous dam, or any other device to provide short term sedimentation.

4. This is a calendar based model devised to estimate the average concentration of runoff produced by the precipitation occurring on a specific day. For a storm which occurs on two or more successive days, each day will be handled separately.

TABLE 3. FACTORS IDENTIFIED TO HAVE AN INFLUENCE ON THE QUALITY OF CATTLE FEEDLOT RUNOFF

Factor	Influence
Rainfall intensity	The processes whereby rainfall strikes a manure covered surface and carries a portion of the material away in the runoff include erosion and extraction. The erosion process is a function of runoff velocity which is increased by higher rainfall intensities. Thus for those constituents primarily related to particle transport, increased intensity may be expected to cause an increase in removal. This phenonemon will be moderated in this model due to the assumed presence of a debris basin between the lot and the retention basin for the removal of coarse solids and readily removed constituents. The extraction phenomenon is of importance in determining the concentration of soluble species in runoff. Since these species are only slightly influenced by sedimentation the time water is in contact with the manure covered surface is of major importance. This contact time will be a function of rainfall intensity which is typically only available in terms of the daily rainfall quantity. Thus, the intensity input to quality will be handled as a function of daily rainfall measurement.
Rainfall quantity	Like intensity, rainfall quantity influences runoff quality. The impact of rainfall quantity is primarily one of dilution. Once flow is established over the surface of a feedlot, physical changes occur on the lot surface which cause subsequent rainfall to runoff

(continued)

TABLE 3 (continued)

Factor	Influence
	without extensive contact with the surface material. This water serves primarily to dilute the runoff. Since the above consideration is based upon single storm considerations and the input data for this model will be daily rainfall records, the second and subsequent rainfall days of a series will require separate handling.
Temperature	Like other biological and physical processes, feedlot runoff generation is influenced by the temperature at which it occurs. Elevated temperatures tend to increase biological activity such as conversion of organic nitrogen (Org-N) to NH_3-N, stabilization of biologically available organic matter and the dieoff of enteric microorganisms. Simultaneously, increased temperature speeds the rate of drying of a feedlot surface. Since both moisture and warmth promote biological activity the lack of either may restrict changes in the quality of runoff. Temperature also influences the physical process of extraction and influences the rate at which soluble constituents enter the water solution.
Antecedant moisture	Runoff from feedlots that are wet prior to the initiation of a rainfall event is of increased solute concentration due to the tendency of the water to approach saturation and to be more available for removal. This phenomenon causes the runoff quality from the early stages of an intense storm to more nearly resemble that from a low intensity storm.
Lot surface	Runoff from hard-surfaced feedlots (concrete) is consistently more concentrated than that from dirt surfaced lots in which the animal hooves mix the manure with soil and in which there are hoof marks which tend to provide some treatment to the runoff before it leaves the lot.

TYPING GUIDE SHEET

The physical, chemical, and microbiological quality of cattle feedlot runoff has been demonstrated to be highly variable. This variability occurs not only among sites and separate storms but during the progress of a runoff event as well. Runoff quality data, gathered by a variety of researchers are tabulated in Appendix A.

These data suggest that although there is extensive variability in the data and that this variability is due to a variety of climatic and geographic inputs as well as feedlot design and management factors, this variability is not random but subject to logical analysis. The purpose of this section of the report is to organize existing feedlot runoff quality predicting information into a format which allows it to be used as an input into the system which predicts the quality of water in a runoff retention basin on a daily basis. This discussion will be based on predicting the quality of water entering the runoff retention basin after having passed through a debris basin or some other means of removing coarse solids. Furthermore, in order to develop a technique which will utilize readily available daily climatic records, daily mean concentrations will be predicted rather than hourly concentrations. Using this approach, this analysis can be combined with existing quantity models to predict the mass of particular constituents entering a basin on the day under consideration. When this input is then mathematically added to the quantity of that constituent already in the basin, a revised concentration can be calculated.

The list of factors influencing feedlot runoff quality is probably lengthy and well beyond current analytical capabilities. However, a few principal input variables can be considered for which the logic has become established. The inputs considered in this analysis include:

1. Lot surface. Early data by Miner (1967) indicated that runoff from concrete surfaced feedlots was consistently more concentrated in organic matter, solid particles, and enteric microorganisms than that from a dirt lot. Due to the mixing of soil with manure on a dirt lot, less of the manure is available for transport. Secondarily, the action of animal activity on a dirt lot is to form numerous indentations serving as sedimentation basins to reduce pollutant concentrations.

2. Lot slope. Increased feedlot slope decreases the time which water spends in contact with the manure covered surface, hence reduces the extraction process. Greater slope also increases the flow velocity which leads to greater erosion transport of solids. No data exist correlating runoff quality as a function of lot slope. The impact of a debris basin is to minimize the effect

of lot slope, hence, it is not considered as an input in this model.

3. Lot temperature. Increased lot surface temperature leads to increased solubility and to increased biological activity so long as moisture is present. Increased temperature will therefore lead to more rapid die-off of enteric bacteria and increased rates of drying, hence, an interaction between temperature and moisture must be considered.

4. Lot moisture. Moisture is important in determining the quality of feedlot runoff for several reasons. Moisture speeds the rate at which soluble manure constituents enter the runoff water. Hence, moist lots produce a higher concentration of organic matter in the runoff. Lot moisture is also essential in the biological activity of a lot which increases NH_3-N concentrations.

5. Rainfall or snowmelt runoff. Runoff due to the melting of snow is significantly more heavily laden with transported manure components than rainfall runoff but is also of lesser quantity. The quality of snowmelt runoff will be estimated separately from rainfall runoff.

ESTIMATING THE COD CONCENTRATION

The COD of cattle feedlot runoff was estimated by Miner, et al. (1966) based upon data taken from two experimental feedlots near Manhattan, Kansas. That correlation was as follows:

$$COD = C_{COD} \left(\frac{1}{R}\right)^{1/3} (k_t)\ (k_m) \qquad (2)$$

where:

COD = average COD concentration in the runoff during a particular storm, mg/ℓ

C_{COD} = base level COD, mg/ℓ

14,000 mg/ℓ for concrete lots

7,000 mg/ℓ for nonsurfaced lots

k_t = temperature correction factor

$10^{(0.014t - 1.12)}$

t = air temperature, °F*

$40 \leq t \leq 80$

k_m = lot moisture correction factor

Lot condition	km
Dry	0.6
Moist	0.8
Wet	1.0

R = rainfall intensity, in/hr

An alternate form for predicting the COD concentration of rainfall runoff was developed by Manges, et al. (1975) based on their work on a concrete surfaced feedlot in western Kansas. That equation is as follows:

$$COD = 65{,}313 + 18.37t - 482M_5 - 1{,}033Tg + 4.387W_5 \quad (3)$$

where:

COD = chemical oxygen demand concentration, mg/ℓ

t = time since runoff began, minutes

M_5 = 5 day anticident moisture, cm

Tg = mean daily ground temperature, °C

W_5 = total wind travel for 5 days prior to the runoff event, km

It was reported (Manges, et al., 1975) that 40 percent of the variation in COD concentration could be attributed to changes in ground temperature.

In order to develop a rational equation for the prediction of COD concentrations in feedlot runoff due to rainfall, the general form of the Universal Soil Loss Equation was adopted. This provides maximum flexibility and maintains the rational philosophy essential to the success of this activity. The equation is as follows:

---

*The basic system of units in this report is SI. When quoting from literature reporting in English units, the English has been preserved. If tabulating data collected in English units, those are also preserved. A conversion table is provided in Appendix H.

$$\mathrm{COD} = \mathrm{COD}_{\mathrm{BASE}}\ K_I K_T K_M K_L K_P \tag{4}$$

where:

COD = COD concentration, mg/ℓ for the day under consideration

$\mathrm{COD}_{\mathrm{BASE}}$ = average or baseline COD concentration in surface runoff, mg/ℓ

K_I = rainfall intensity factor

$= \left(\frac{r}{254}\right)^{-0.4}$

r = daily rainfall, mm

K_T = temperature factor

$= 10^{(0.018T_S - 0.38)}$

T_S = lot surface temperature °C approximated by

$$\frac{5To + 4T_1 + 3T_2 + 2T_3 + T_4}{15}$$

To = average air temperature on day in question, °C

T_1 = average air temperature 1 day earlier, °C

T_2 = average air temperature 2 days earlier, °C

K_M = lot moisture factor as defined in Table 4

K_L = lot surface material factor

= 1.0 for dirt surfaced lot

= 1.8 for concrete surfaced lot

K_P = source of runoff factor

= 1.0 for rainfall

= 5.0 for snowmelt

TABLE 4. FORM OF LOT MOISTURE CALCULATIONS

LMHC = lot moisture holding capacity, mm

50 mm for surfaced
100 mm for non-surfaced

LM = lot moisture on any day, mm

PRECIP = daily precipitation, mm

RUNOFF = daily runoff, mm

PETBS = daily potential evapotranspiration for a bare surface, mm of water

PF = proportioning factor for lot moisture evaporation for dry conditions where,

$PF = 1.0$ if LM equal or greater than 0.5 (LMHC)

$PF = \frac{2.0\ (LM)}{LMHC}$ if LM less than 0.5 (LMHC)

If LM greater than LMHC, LM set equal to LMHC

K_M = lot moisture correction factor

$$K_M = 0.5\ (1.0 + LM/_{today})$$

$$LM_{today} = LM_{yesterday} + PRECIP_{yesterday} - RUNOFF_{yesterday} - PETBS(PF)_{yesterday}$$

ESTIMATING N CONCENTRATIONS

The Total-N concentration of feedlot runoff like COD is related to the organic matter on the feedlot and the mechanisms of its removal. Miner, et al. (1966) used an equation of the same form as that for COD to correlate Total-N concentrations to rainfall rate, temperature and lot moisture. Their work indicated Total-N equalled four to five percent of the COD. Manges, et al. (1975) utilized the following equation:

$$N = 0.091\ COD - 137 \tag{5}$$

where:

N = Total-N concentration, mg/ℓ

The Total-N concentration is estimated using an equation of the same form as that used for the COD concentration. That equation is as follows:

$$NTOT = N_{BASE}\ K_I K_T K_M K_L K_P \qquad (6)$$

where:

$NTOT$ = Total-N concentration, mg/ℓ

N_{BASE} K_I, K_T, K_M, K_L and K_P are the same as defined for COD estimation

The TKN concentration in feedlot runoff includes a portion present as dissolved NH_3-N and the remainder as more complex N containing organic molecules. The proportion of the TKN present as NH_3-N is a function of the extent to which biological activity within the manure accumulated on the feedlot surface has undergone ammonification and the degree to which NH_3-N has volatilized. Lot moisture and temperature are the most important variables in predicting the fraction of Total-N to be in the NH_3-N form.

Various measurements of the (NH_3-N)/(Total-N) quotient have been reported. Miner (1966) reported values ranging from 0.1 to 0.4 during the summer in Kansas and 0.01 to 0.05 during the winter. Other data seem to confirm these ranges. The following technique is proposed to predict NH_3-N concentrations.

$$NH_3 = FNH3\ (NTOT) \qquad (7)$$

where:

NH_3 = concentration of NH_3-N, mg/ℓ

$FNH3$ = fraction of Total-N concentration present as NH_3-N

$NTOT$ = Total-N concentration, mg/ℓ

The following technique will be used to predict FNH3

$$FNH3 = K_{FRAC}\ (K_T\ (LM/LMHC))^2 \qquad (8)$$

where:

K_T = temperature correction factor as defined for COD

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

$= 10^{(0.018T_s - 0.38)}$

T_s = lot surface temperature, °C, as defined earlier

LM = lot moisture at the start of any day, as defined in Table 4

LMHC = lot moisture holding capacity, as defined in Table 4

ESTIMATING PHOSPHOROUS (P) CONCENTRATIONS

P although present in retention basin influent in much lower concentrations than either COD or N is related to COD. The concentration was correlated to COD by Manges (1975) by the following relationship and correlation coefficient.

$$P = 0.036\ \text{COD}-153 \qquad r = 0.64 \qquad (9)$$

The following expression is proposed for predicting Total-P concentration.

$$P = P_{BASE}\ K_I K_T K_M K_L K_P \qquad (10)$$

where:

P = phosphorous concentration as P, mg/ℓ

K_I = rainfall intensity factor as defined for COD

K_T = temperature factor as defined for COD

K_M = lot moisture factor as defined for COD

K_L = lot surface material factor as defined for COD

K_P = source of runoff factor as defined for COD

ESTIMATING SOLIDS CONCENTRATIONS

Since the solids concentration parameters in feedlot runoff are not entirely different materials than those being measured as COD, biochemical oxygen demand (BOD), and salts, these predictions must incorporate the logic devised for those constituents. Manges (1975) developed the following relationships and correlation coefficients.

$$TS = 2.74\ \text{COD}-11{,}120 \qquad r = 0.52 \qquad (11)$$

$$TVS = 1.08\ \text{COD}-2{,}132 \qquad r = 0.84 \qquad (12)$$

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

In addition to the considerations involved in COD prediction, solids concentrations should consider the accumulation of soluble inorganic ions in the lot surface materials during extended arid conditions.

$$FDS = FDS_{BASE}\ K_I K_T K_M K_L K_P K_{SA} \tag{13}$$

where:

FDS = fixed dissolved solids concentration, mg/ℓ. Includes the standard inorganic cations - Na, K, Ca, Mg and their associated anion normally contributing to salinity

K_I = rainfall intensity factor as defined for COD

K_T = temperature factor as defined for COD

K_M = lot moisture factor as defined for COD

K_L = lot surface material factor as defined for COD

K_P = source of precipitation factor as defined for COD

K_{SA} = salt accumulation factor

$$= 1 + \frac{\text{average annual lake evaporation}}{\text{average annual precipitation}}$$

In addition to the FDS which account for the soluble inorganic ions in settling basin overflow there is an organic solids fraction which will be identified as TVS. TS in the retention basin shall be postulated as the sum of FDS plus TVS. TVS concentrations are related to the COD hence will be predicted by a similar expression.

$$TVS = TVS_{BASE}\ K_I K_T K_M K_L K_P \tag{14}$$

where:

TVS = total volatile solids concentration, mg/ℓ

K_I = rainfall intensity factor as defined for COD

K_T = temperature factor as defined for COD

K_M = lot moisture factor as defined for COD

K_L = lot surface material factor as defined for COD

K_P = source of runoff factor as defined for COD

$$TS = TVS + FDS \tag{15}$$

where:

TS = total solids, mg/ℓ

ESTIMATING BACTERIAL CONCENTRATIONS

Only limited data exist on the various bacterial concentrations in feedlot runoff. Miner (1967) reported TC, FC and FS counts using most probable number (MPN) techniques under a variety of climatic conditions. Bacterial concentrations in runoff are controlled in part by the same parameters as organic matter, however there is an additional temperature influence. Warmer temperatures speed the die-off of enteric microorganisms. Hence, the following form is proposed.

$$RTCOLI = 75 \times 10^6 \, K_I K_M K_L K_P K_{TB} \tag{16}$$

$$RFCOLI = 35 \times 10^6 \, K_I K_M K_L K_P K_{TB} \tag{17}$$

$$RFSTRP = 25 \times 10^6 \, K_I K_M K_L K_P K_{TB} \tag{18}$$

where:

$RTCOLI$ = TC concentration, number per 100 ml

$RFCOLI$ = FC concentration, number per 100 ml

$RFSTRP$ = FS concentration, number per 100 ml

K_I = rainfall intensity factor

$= r^{-0.4}$

r = daily rainfall, in.

K_M = lot moisture correction factor as defined in Table 4

K_L = lot surface material factor as defined for COD

K_P = source of runoff factor as defined for COD

K_{TB} = temperature correction factor for bacteria in runoff

$= 10^{(0.8 - 0.04\, T_S)}$

T_S = lot surface temperature as defined for COD

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 6

MODELING THE RETENTION POND LIQUID QUALITY

Since feedlot runoff cannot be discharged to a stream, it is caught and stored in a retention pond until it can be spread onto land. The natural treatment that takes place in the retention pond can be likened to that in an anaerobic lagoon. Manges, et al. (1975) described the effects they found. The values of COD for a sample collected 15 cm (6 in) below the surface is shown in Figure 3. They described the surface samples to represent that part of the pond which would be effluent if a discharge occurred or if it were taken off for disposal by irrigation. The early spring samples from the pond exhibited the greatest values of COD, N, and P. This was also true of the runoff. After a period of heavy rains in late May and early June, the COD in the pond was about 6000 mg/ℓ. Over the following 60-day period, when there was no significant runoff, the COD at the pond surface was reduced by about 65 percent. At the same time the lagoon contents were being reduced by seepage and evaporation which had a concentrating effect on the pollutional parameters. The TS showed a gradual increase from about 4000 mg/ℓ at the beginning of the period to about 7000 mg/ℓ 60 days later with no significant inflow. Total-N and P did not show any great change during this period. Solids on the bottom of the pond were actively decomposing as indicated by bubbling action that was noted to occur. This bubbling action would also have the effect of keeping the lagoon contents partially mixed.

Dickey and Vanderholm (1976) studied runoff control systems from six livestock operations in northern and central Illinois. Holding pond water quality for one of the ponds was sampled weekly and the contents of the other five holding ponds were sampled monthly. Samples were taken near the surface and near the bottom approximately at the center of each pond so values reported would be expected to represent averages of liquid quality. Measurements made included NH_3-N, TKN, nitrate plus nitrite nitrogen (NO_3+NO_2-N), Total-P, total potassium (Total-K), total sodium chloride (NaCl), electrical conductivity (EC), COD, TS, and total suspended solids (TSS). Included herein are the data from Holding Pond Number 1 which is from a beef unit (Figures 4 through 10). Since other pertinent information about the quantity of liquid within the retention pond, the physical size of the feedlot, the holding capacity of the runoff retention basin, and runoff volume into the basin during the season

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT HERE
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-74)

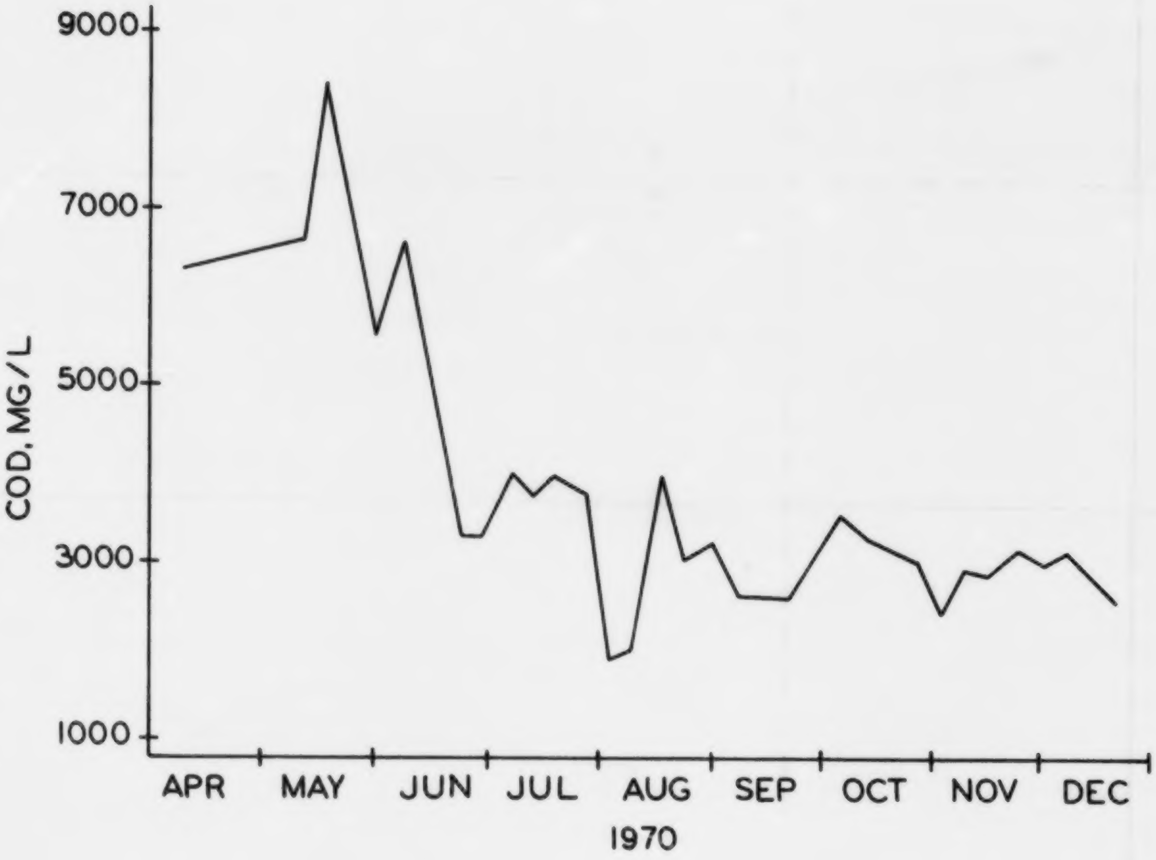

Figure 3. Influence of season on COD 15 cm (6 in) below the surface of Lagoon 119 receiving cattle feedlot runoff at Pratt, Kansas (Manges, et al., 1975).

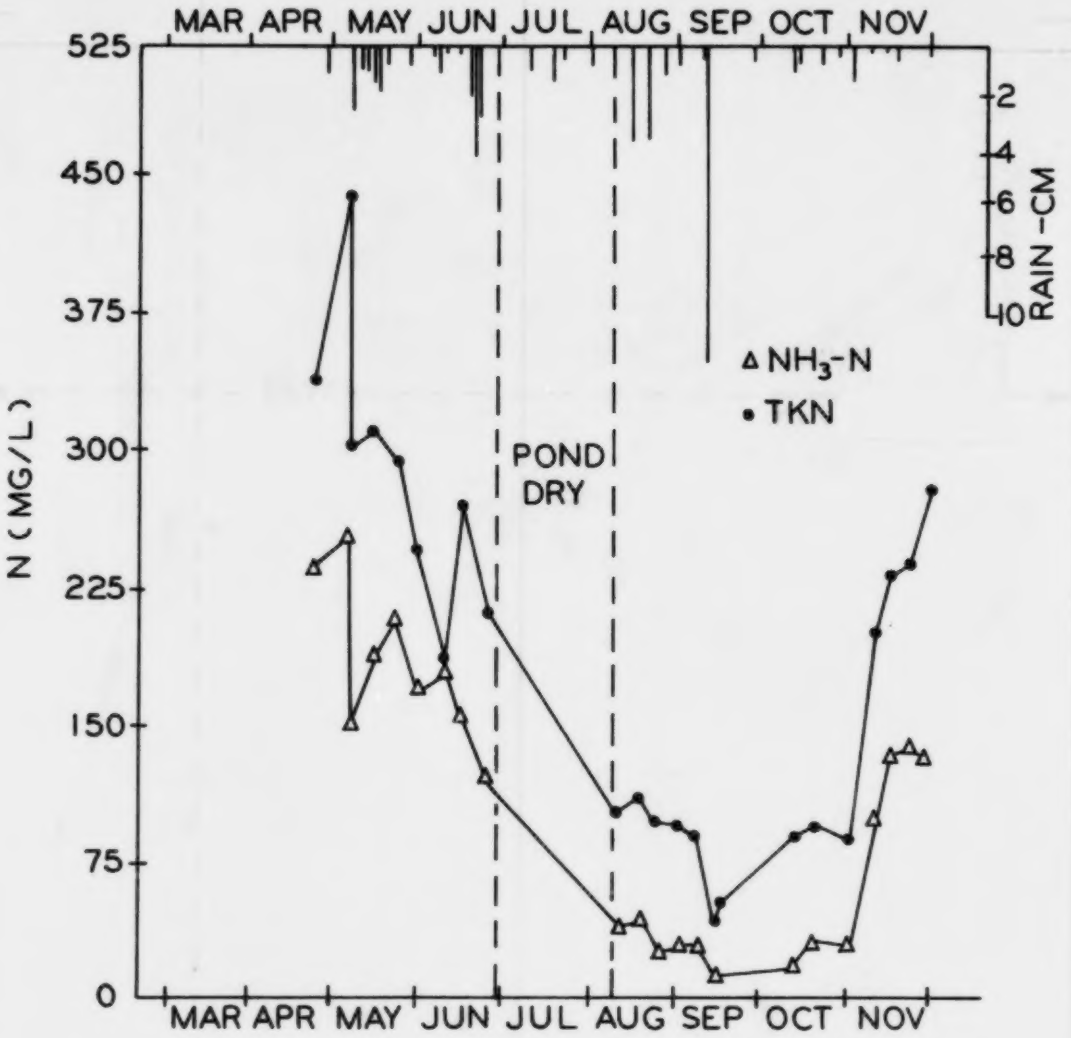

Figure 4. Daily rainfall and changes in N concentrations during 1974 in a holding pond for beef (Dickey and Vanderholm, 1976).

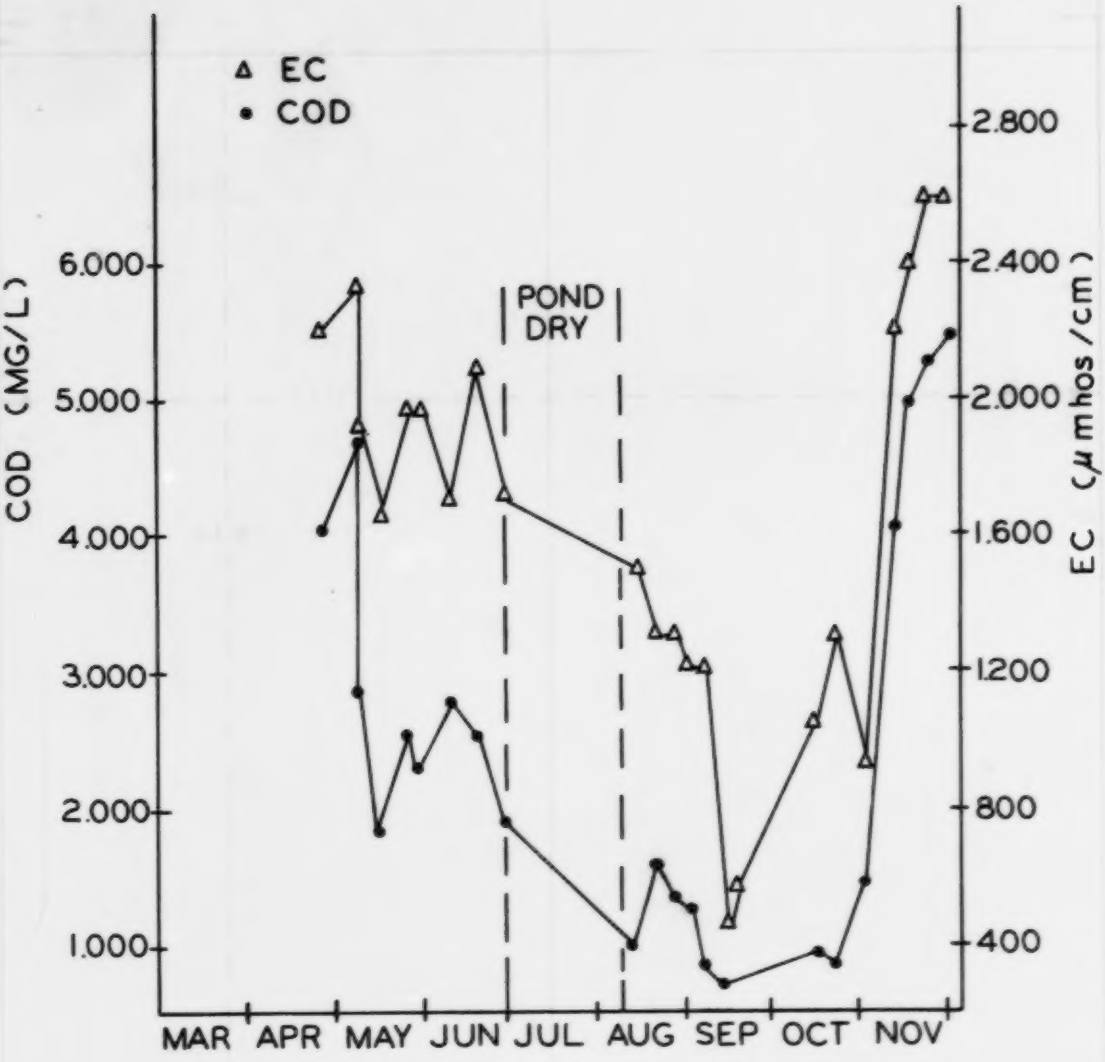

Figure 5. Seasonal changes in the EC and COD in a holding pond during 1974 for beef feedlot runoff (Dickey and Vanderholm, 1976).

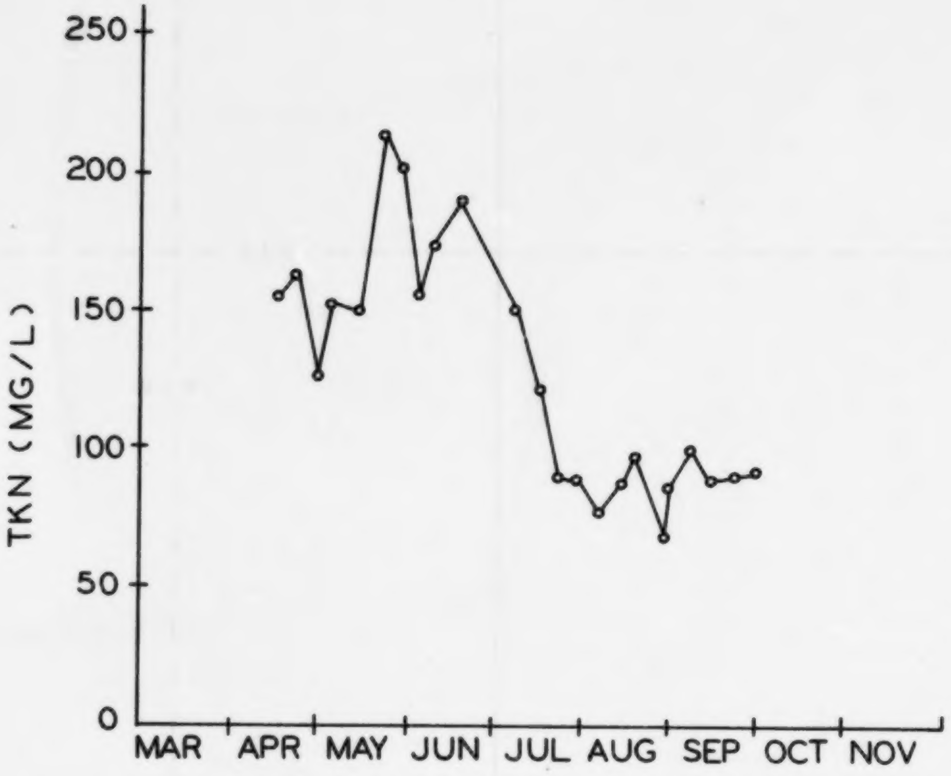

Figure 6. Seasonal variation of TKN in a holding pond for beef feedlot runoff during 1975 (Dickey and Vanderholm, 1976).

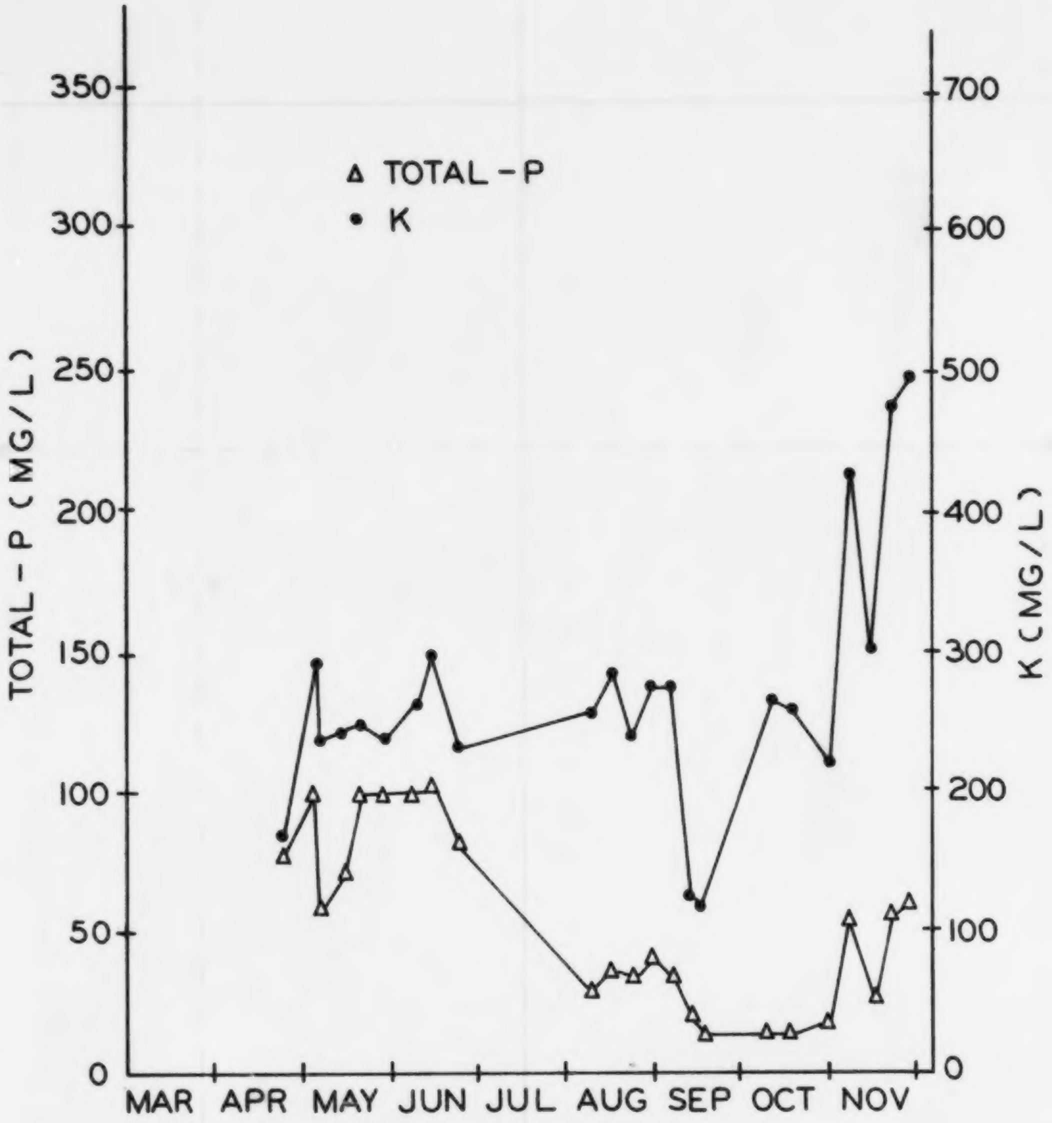

Figure 7. Seasonal changes in Total-P and K concentrations in a holding pond for beef feedlot runoff during 1974 (Dickey and Vanderholm, 1976).

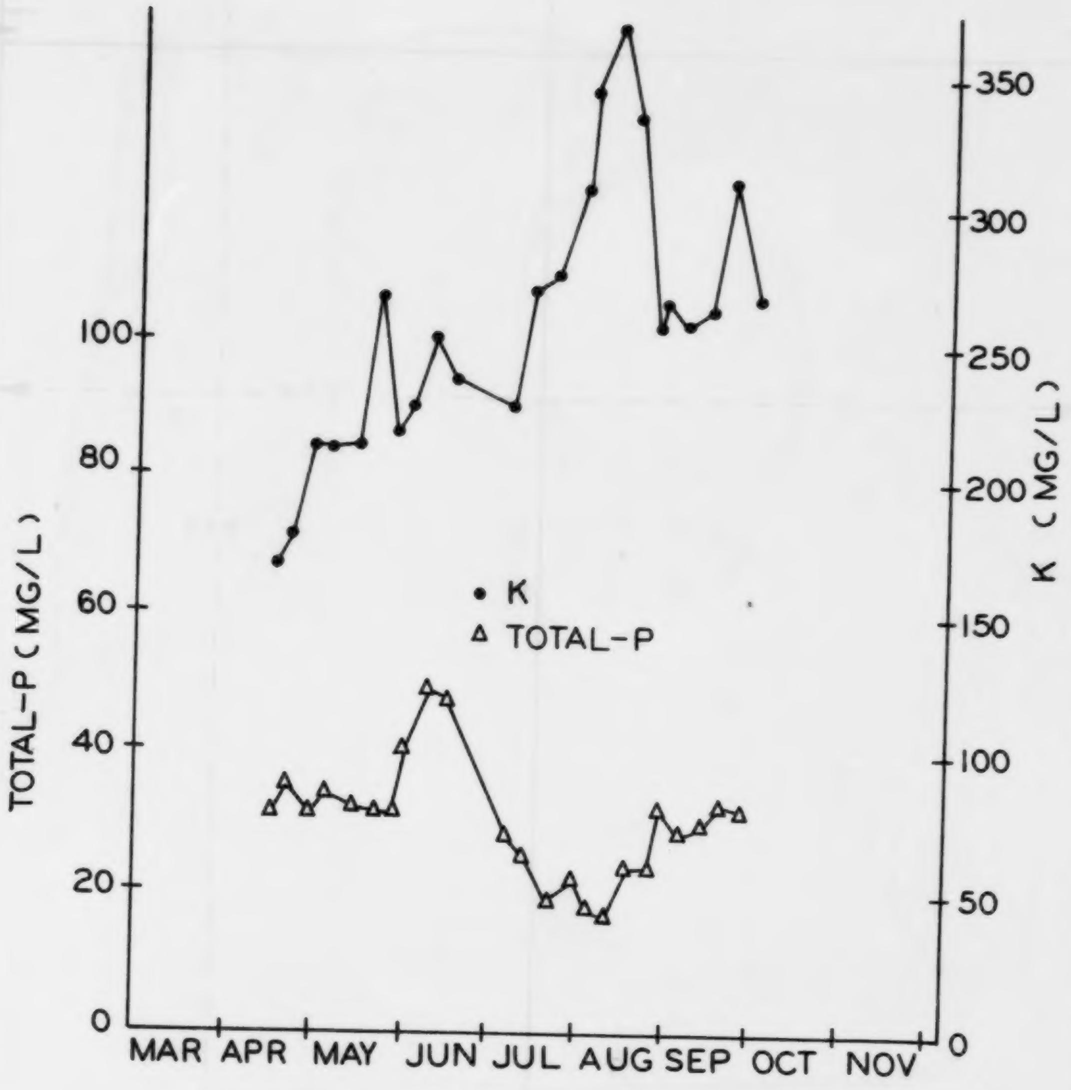

Figure 8. Seasonal changes in Total-P and K concentrations in a holding pond for beef feedlot runoff during 1975 (Dickey and Vanderholm, 1976).

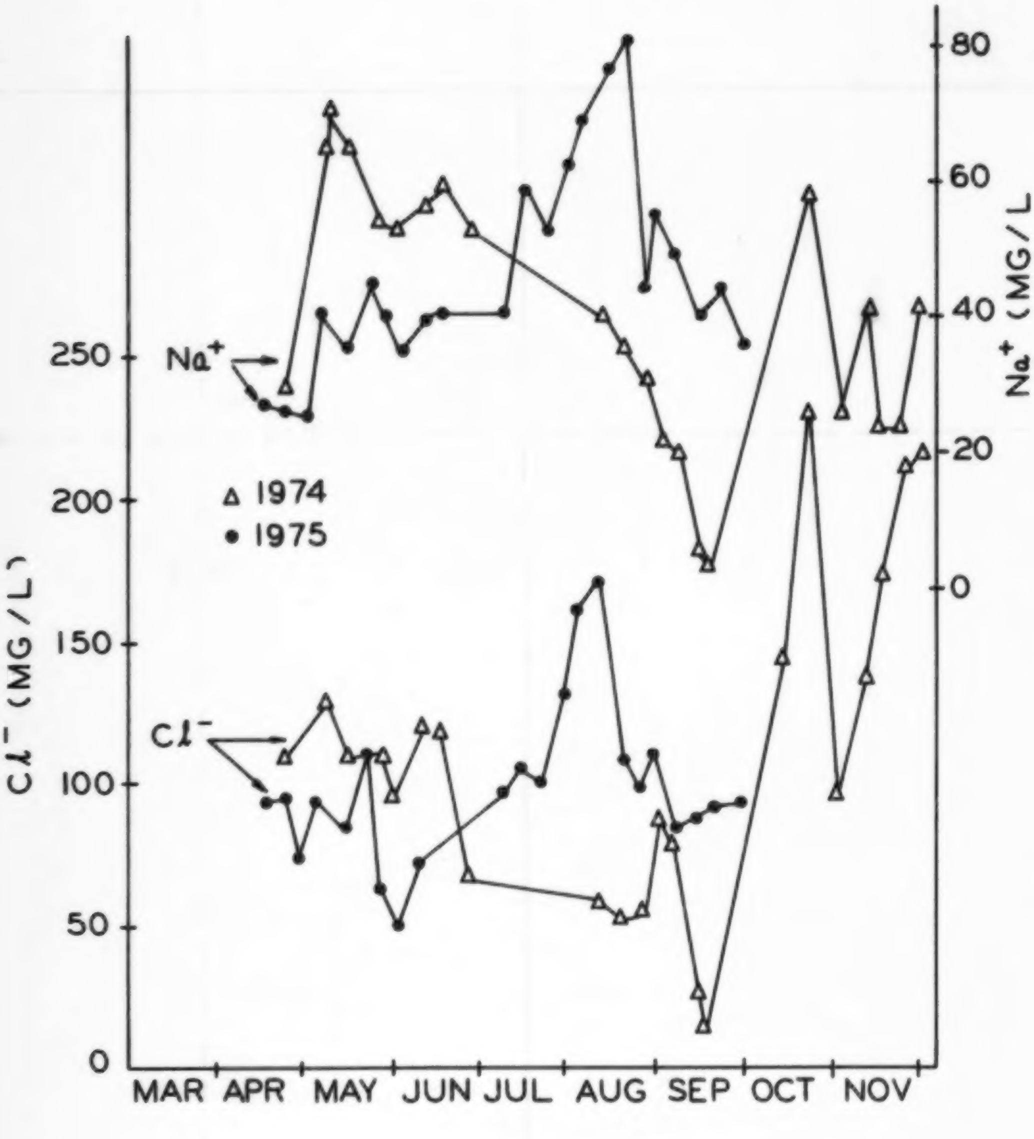

Figure 9. Seasonal changes in Na^+ and Cl^- concentrations in a holding pond for beef feedlot runoff (Dickey and Vanderholm, 1976).

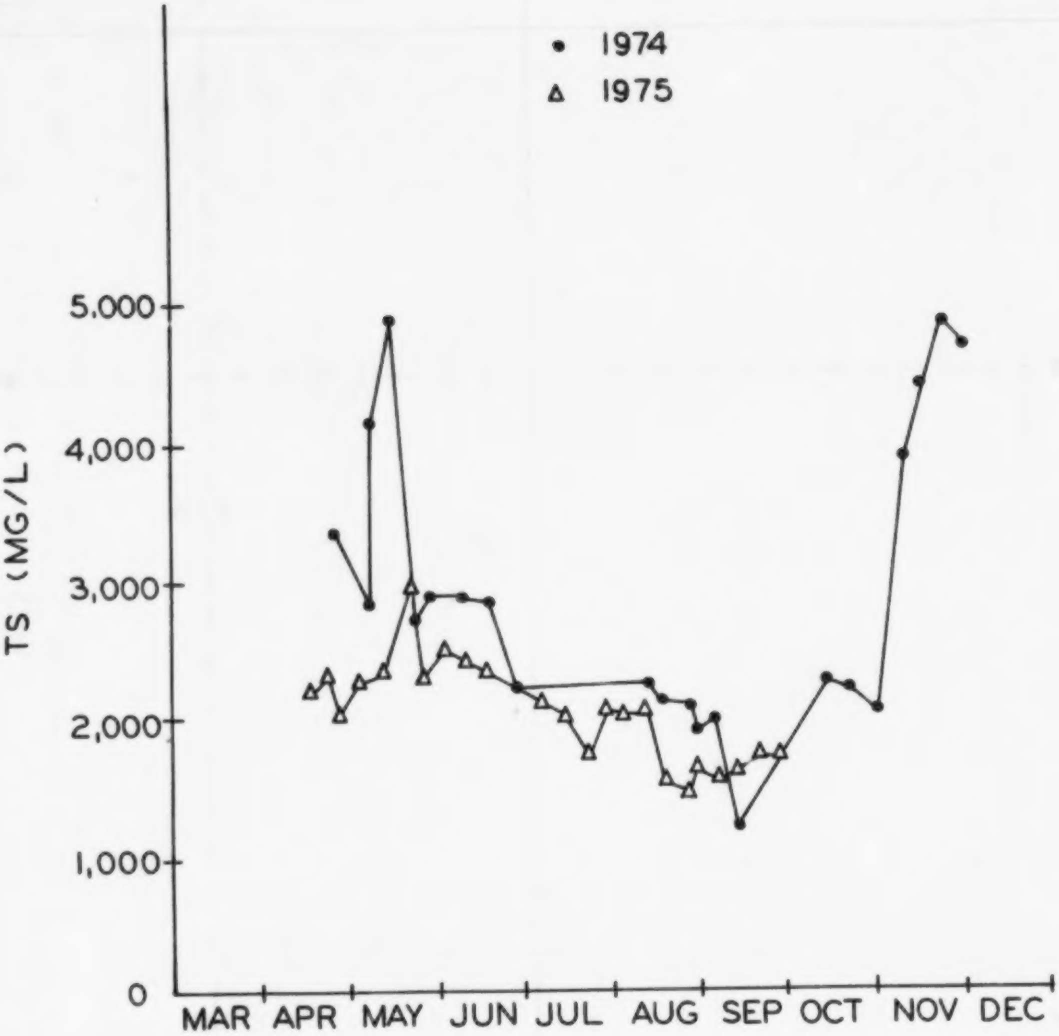

Figure 10. Seasonal variation in the TS concentrations in a holding pond for beef feedlot runoff (Dickey and Vanderholm, 1976).

are not known in similar detail, these data can be used only to show general trends in the change in quality within the retention basin (holding pond) over the season. However, these data represent the most complete set of liquid quality data from a runoff retention pond that has been reported. More detailed discussion of each constituent will be included in the following section as they are used in development of the preliminary water quality model for the retention basin.

Other researchers have periodically sampled liquid in runoff retention ponds; however, such data is of limited value in development of a water quality model. A single observation in time without a previous history of the contents of the retention basin does little more than provide a value that will fit into a range over which the magnitude of the particular constituent could be expected to vary.

CHEMICAL OXYGEN DEMAND

COD, which is a measure of organic strength of the contents of the retention basin is subject to biological degradation over time. The rate at which such degradation will occur will be dependent upon the temperature of the liquid, the rate at which the microorganisms can attack and consume the organic materials, the rate at which any suspended materials that contain COD will settle, and the rate at which settled solids will be reliquified in a biological process. Data from Manges, et al. (1975) and Dickey and Vanderholm (1976) show a rapid decrease in the COD of the retention pond liquid over the summer as the liquid temperature increased.

COD from the feedlot runoff surface flows through a sedimentation basin and finally enters the retention pond as shown in Figure 11. In the retention pond it is split into two components--one which will settle and become part of the sludge or solids accumulation within the pond, and a second fraction which remains in solution in the retained liquid. The exact split will depend upon the lot conditions, particularly the temperature as it has affected the degradation of materials on the lot surface, hydraulic detention time within the settling basin ahead of the runoff pond, and perhaps the amount of runoff that has occurred in the past few days. As a first approximation, about 40 percent of the COD might be expected to settle from the liquid.

Considering the portion that has settled in the pond, there will be a fraction that can be liquefied and enter the liquid system as COD plus an inert fraction which will remain as sludge in the pond. As first estimate, about 70 percent of the settled solids might be reliquefied and add COD to the liquid. The process is, of course, anaerobic decomposition. However, the end result is nearly complete release of COD measured materials into

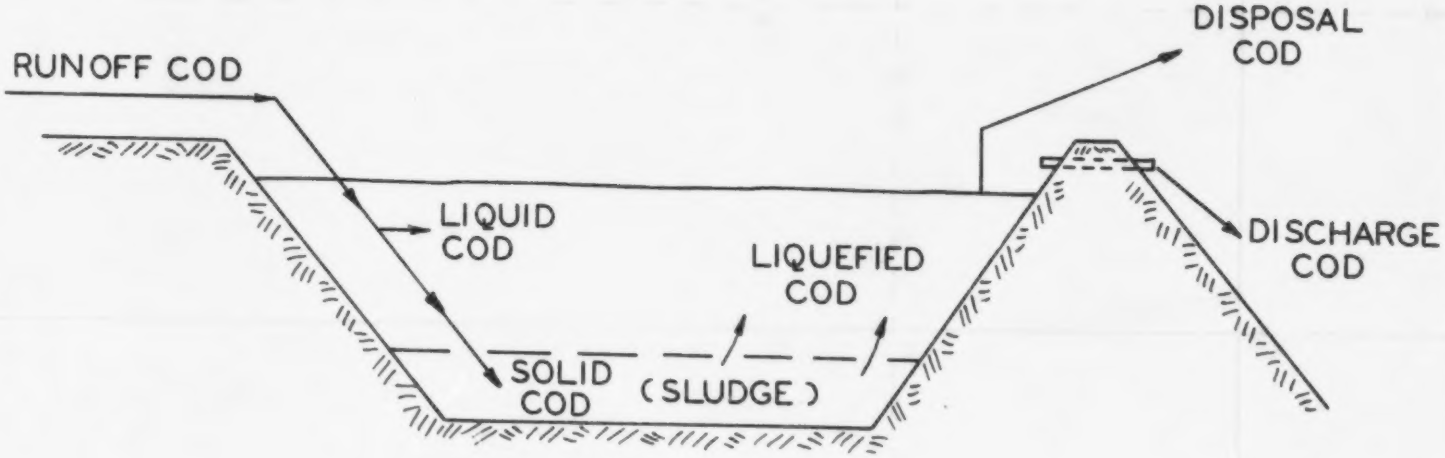
RUNOFF COD
LIQUID COD
SOLID COD
(SLUDGE)
LIQUEFIED COD
DISPOSAL COD
DISCHARGE COD

Figure 11. COD accounting for feedlot runoff retention basin.

the liquid. The remaining 30 percent would be inert and accumulate as sludge. Studies by Oswald, et al. (1963) show that gas production as a function of temperature range from about 12 to 20°C. Based upon these data, the liquefication KL_{PT} factor is estimated to be $KL_{PT} = KL_{20} \times 1.45 (T - 20)$, where KL_{PT} is in units of $days^{-1}$ and PT = temperature, °C of the pond liquid. KL_{20} is estimated to be 0.005.

The amounts of solids that can be liquefied is accumulated and accounted for on a daily basis. Then, this KL_{PT} value would be applied to a first-order rate degradation equation to the mass of degradable solids. The COD liquefied each day = (Total-COD in liquefiable form) x $10^{-KL_{PT}}$. The amount of COD liquefied by this route would then be considered to be released into the liquid where it would be degraded according to the liquid degradation function.

The inert solids will accumulate as sludge. Therefore, sludge is estimated to be equal to the accumulated inert COD. It is estimated that 1 kg of COD will produce 1 ℓ of sludge.

In the liquid phase of the pond, the COD degradation would be according to a first-order rate equation. Temperature effects on waste degradation rate in oxidation ponds is shown to be similar to that of other microbial systems. The equation there is $KC_{PT} = KC_{20} \times 1.07^{(T - 20)}$, where KC_{PT} = degradation coefficient, $days^{-1}$ and PT = liquid temperature, °C. This relationship appears to hold from about 3 to 35°C (Hermann and Gloyna, 1958). An approximation of the rate or KC_{PT} factor from data collected by Manges, et al. (1975) at Pratt, Kansas (see Figure 3) indicates that the KC_{20} factor is approximately 0.015 $days^{-1}$. This relationship was developed for the liquid COD near the surface of a runoff retention pond. Therefore, the KC_{20} value also includes a rate sufficient to degrade the contribution from solids that were liquefied during this period.

Just as with the COD and the settled solids, there is probably some fraction of the liquid COD that is relatively nondegradable. This fact can be seen from the COD versus time graphs for a runoff retention pond as shown in Figures 3 and 5. Over the summer months, the COD concentration reached a level and remained quite constant throughout the summer period. From these data, it appears that approximately 50 percent of the incoming COD that remains in the liquid could be characterized as nondegradable. Therefore, the degradation equation for reducing the COD in the liquid does not consider that portion to be acted upon in the degradation equation. An initial estimate is that 30 percent of the COD in the incoming runoff is essentially nondegradable.

To model the COD changes within the pond, these additional terms are defined:

$$PCOD = LCODT\ (1000/PONVOL) \qquad (19)$$

$$LCODT = LCODD + LCODN$$

$$\begin{aligned} LCODD = {} & LCODD\ (1 - 10^{-KC_{PT}}) + (RCOD \times A) - \\ & \{LCODD \times DISVOL/(DISVOL + PONVOL\} - \\ & \{(RCOD \times A) + LCODD\} \times DSCHRG/(DSCHRG + \\ & PONVOL) + SCODL \times (1-10^{-KL_{PT}}) \end{aligned} \qquad (20)$$

$$\begin{aligned} LCODN = {} & LCODN + (RCOD \times B) - \{LCODN \times DISVOL/ \\ & (DISVOL + PONVOL)\} - \{(RCOD \times B) + LCODN\} \times \\ & DSCHRG/(DSCHRG + PONVOL) \end{aligned} \qquad (21)$$

$$RCOD = RUNOFF \times CCOD/1000$$

$$SCODL = SCODL + RCOD \times C - SCODL \times 10^{-KL_{PT}} \qquad (22)$$

$$SCODN = SCODN + RCOD \times D$$

$$LCODT = LCODD + LCODN$$

$$PCOD = LCODT \times 1000/PONVOL$$

$$SLUDGE = SCODN/1000$$

where:

LCODD = degradable COD in liquid, kg/ha

LCODN = nondegradable COD in liquid, kg/ha

SCODL = liquefiable COD in the settled solids, kg/ha

SCODN = nonliquefiable COD in the settled solids, kg/ha

CCOD = average COD in feedlot runoff, mg/ℓ for the particular day under consideration

RCOD = COD contained in feedlot runoff, kg/ha, for the particular day under consideration

LCODT = total amount of COD in liquid, kg/ha

PCOD = concentration of COD in retention basin liquid, mg/ℓ

SLUDGE = total volume of solids accumulated on the pond floor, m^3/ha

PONVOL = volume of liquid in holding pond, m^3/ha at the end of the particular day under consideration

RUNOFF = volume of feedlot runoff, m^3/ha for the particular day under consideration

T = average air temperature on day in question, ^oC

T_i = average air temperature i days earlier, ^oC

A,B,C,D = factors for splitting RCOD into LCODD, LCODN, SCODL, SCODN $\Sigma(A + B + C + D) = 1$

$$PT = \frac{T + T_1 + T_2 + T_3 + T_4}{5}$$

NITROGEN

The Total-N concentration in the feedlot runoff retention pond is related to the COD of the liquid. However, the process of accounting for and predicting the N content in the liquid is complicated by the fact that NH_3-N is volatilized from the pond surface. Generally, runoff retenion ponds are anaerobic in nature and do not contain significant amounts of oxidized N. Ponds that are allowed to stand with small amounts of liquid in them for relatively long periods of time may accumulate significant concentrations of oxidized N. However, the total mass of N in this form would be relatively small. In this model, nitrification to nitrite and nitrate forms of N will be assumed to be zero. Subsequently, denitrification is also assumed to be zero.

Data from Dickey and Vanderholm (1976) shown in Figures 4 and 5 show similar trends for COD and Total-N in the runoff retention pond. Averaging the data from nine sampling dates shows that the Total-N was equal to 10 percent of the concentration of the COD for the period of late April to late June. A slight trend could be discerned that the Total-N/COD increased slightly with increasing temperature. Similar analysis for 12 data points from August to late November showed that the ratio of TKN/COD was about 0.06. Here, the trend indicated that as temperatures decreased, the Total-N/COD decreased. Therefore, TKN/COD appears to be somewhat temperature related with higher ratios associated with higher temperatures. Such a trend might be expected because COD breaks down quite rapidly and the subsequent loss of N by volatilization would likely not be as great during the same period. Since COD breakdown, ammonification, and ammonia volatilization all affect the TKN/COD ratio, a model that treats each process separately should also yield a similar trend.

To model the N concentration in retention pond liquid, TKN will be split into components. The first component will be Org-N which is TKN minus NH_3-N. The second component will be NH_3-N. Figure 12 shows the general pathways for both Org-N and NH_3-N.

For Org-N, an approach similar to that used for COD will be considered. The Org-N that enters the retention basin as feedlot runoff will be split into a portion that remains in the liquid and a portion that settles into solids. The split used initially will be the same as used for COD. A first approximation is that Org-N in the various phases is released or stored in proportion to COD fractions. The liquid portion will contain a component of Org-N that can be ammonified and a component which cannot be attacked by ammonifying organisms. Seventy percent was assumed ammonifiable and 30 percent not. The form of ammonification relationship assumed will be similar to that found by Stanford, et al. (1973) for soil conditions. This relationship is

$$\log_{10K} = 7.71 - 2758 \left(\frac{1}{T}\right) \qquad (23)$$

where K = the mineralization rate coefficient, weeks^{-1}; T = the absolute temperature, $^{\circ}$K. For this relationship, K_{20} = about 0.054 weeks^{-1} (0.007 days^{-1}). This rate for soil is likely too low for retention pond liquid because the Org-N in the liquid is likely to be much more amenable to ammonification and the nonammonifiable fraction is not considered in this reaction in this process. The ammonification coefficient, KA_{20}, will be initialized to the coefficient for LCODD, KC_{20} = 0.015 days^{-1}. The portion of Org-N contained in the solids is also split into a portion that can be liquefied and a portion which cannot be liquefied. This split and the subsequent rate of liquefication will be assumed to be the same as that previously developed for COD. Similarly, N contained in the sludge solids will be treated the same as for COD. Sludge volume has already been estimated in the COD portion of the model.

All of the NH_3-N contained in runoff is assumed to go immediately into the retention pond liquid. Additional NH_3-N is added from ammonification of Org-N contained within the liquid. NH_3-N from the liquid is lost by volatilization from the surface of the pond to the atmosphere.

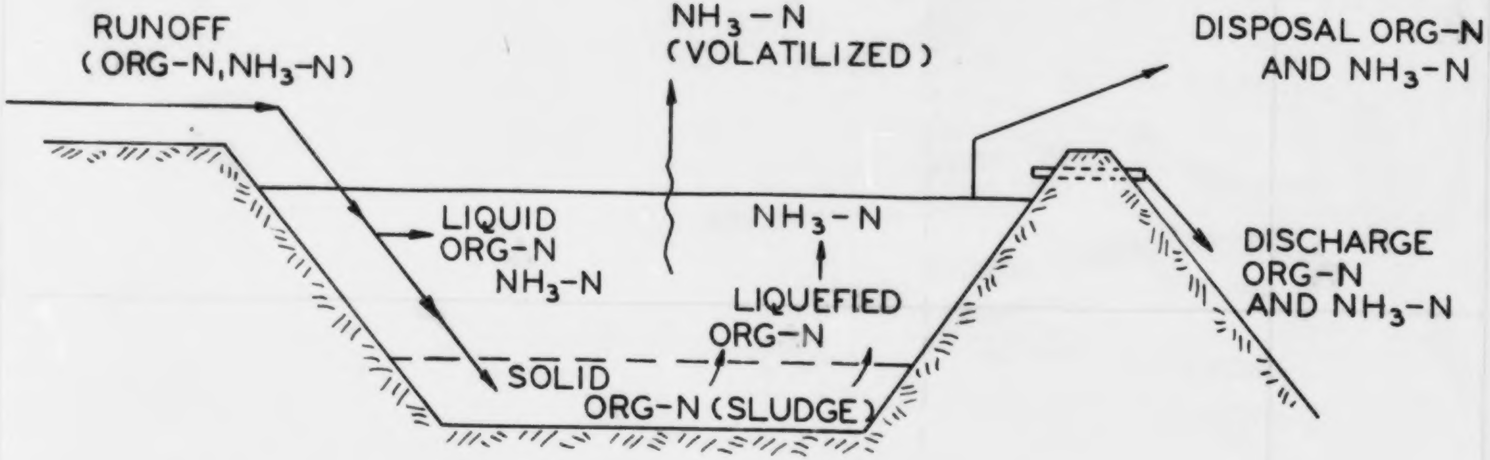
RUNOFF
(ORG-N, NH_3-N)
NH_3 - N
(VOLATILIZED)
DISPOSAL ORG-N
AND NH_3-N
LIQUID
ORG-N
NH_3-N
NH_3-N
LIQUEFIED
ORG-N
SOLID
ORG-N (SLUDGE)
DISCHARGE
ORG-N
AND NH_3-N

Figure 12. N accounting for feedlot runoff retention basin.

The loss of NH_3-N is believed to be substantial from runoff retention ponds that contain liquid over the warmer portion of the year. Figure 4 shows a continuous decrease in Total-N and NH_3-N from May through September for a pond in Illinois. Notice that the Org-N remained quite constant over this period while the NH_3-N concentration dropped sharply. Similar results have been shown for an anaerobic swine lagoon (Koelliker and Miner, 1973). Volatilization of NH_3-N has been found to be the cause of the loss of N. During the warmer months, liquid temperatures increase, pH of the liquid rises and the NH_3-N in the gaseous form in the liquid may increase by ten-fold.

Volatilization of NH_3-N appears to be a function of the retention pond liquid temperature, pH, NH_3-N content, surface area exposed, and the rate of renewal of the gas film over the liquid surface. (Note: for purposes of this presentation, NH_3-N refers to NH_4^+ plus NH_3-N contained in the liquid. It is further shown as NH_3-N in equations.) The process involves only gaseous NH_3-N transfer. The familiar mass transfer relationship is believed to apply for the volatilization process,

$$\frac{d(NH_3 - N)}{dt} = AK\,(P_L - P_g) \tag{24}$$

where:

$NH_3 - N$ = weight of NH_3-N volatilized, kg per ha of feedlot area

t = time, days

A = area of retention pond liquid surface, m^2 (per ha of feedlot)

P_L = partial pressure of NH_3-N in the retention pond liquid, atm

P_g = partial pressure of NH_3-N in air above the retention pond, atm

From previous work by Koelliker and Miner (1973) the relationship for NH_3-N desorption (volatilization) from an anaerobic swine lagoon was developed. A similar approach will be used for the runoff retention pond model.

The overall mass transfer coefficient,

$$K = Kv\ V^{0.8}\ T^{-1.4}\ \frac{\text{lb}}{\text{day-ft}^2\text{-atm}} \tag{25}$$

where:

Kv = a constant

V = the wind speed over the pond surface in ft/sec at 0.6 m (2 ft) above the surface

T = the average daily air temperature, $^{\circ}K$

Here, V will equal the mean monthly wind speed previously adjusted to 2 m (6 ft) height. A log profile will be assumed to adjust it downward to 0.6 m (2 ft). The surface area, A, is today's runoff retention pond liquid surface area based upon today's volume of liquid and its volume to surface area relationship divided by the area of the feedlot.

The driving force, $(P_L - P_g)$, is a measure of the relative partial pressure difference of NH_3-N in the retention pond liquid and the surrounding air. For purposes of this model, it will be assumed that P_g of NH_3-N in the air will be equal to 1×10^{-6} atm. P_L is a function of the concentration of NH_3-N in the solution, the liquid temperature, and the liquid pH. To avoid the seemingly impossible task of predicting the pH of the retention pond liquid, the volatilization rate will be assumed to be a function of the liquid temperature and the concentration of NH_3-N in the retention pond liquid. Data previously published by Koelliker and Miner (1973) for an anaerobic swine waste lagoon will be used to estimate the relationship for P_L as it is influenced by the liquid temperature and NH_3-N concentration in the liquid. The data points used to develop this relationship are shown in Figure 13. The $\log_{10}$ of $P_L/(NH_4+NH_3\text{-}N)$ versus the liquid temperature yields nearly a straight line on the semi-log plot. $\text{Log}_{10}\ [P_L/NH_4^+ + NH_3\text{-}N)] = 0.058\ PT = 3.04$, $R^2 = 0.96$, where

P_L = partial pressure of NH_3-N in the liquid, atm x 10^{-6}

PT = liquid temperature, $^{\circ}C$

$NH_4^+ + NH_3$-N = NH_3-N concentration in the liquid, mg/ℓ

The equation used in this model was therefore

$$P_L = 10^{(0.058\ PT\ -\ 3.04)} \times (NH_4^+ + NH_3\text{-}N) \qquad (26)$$

Since this relationship fits quite well considering only the temperature, neglecting the pH of the liquid may not result in a serious error.

To model N changes in the retention pond liquid, these additional terms are defined:

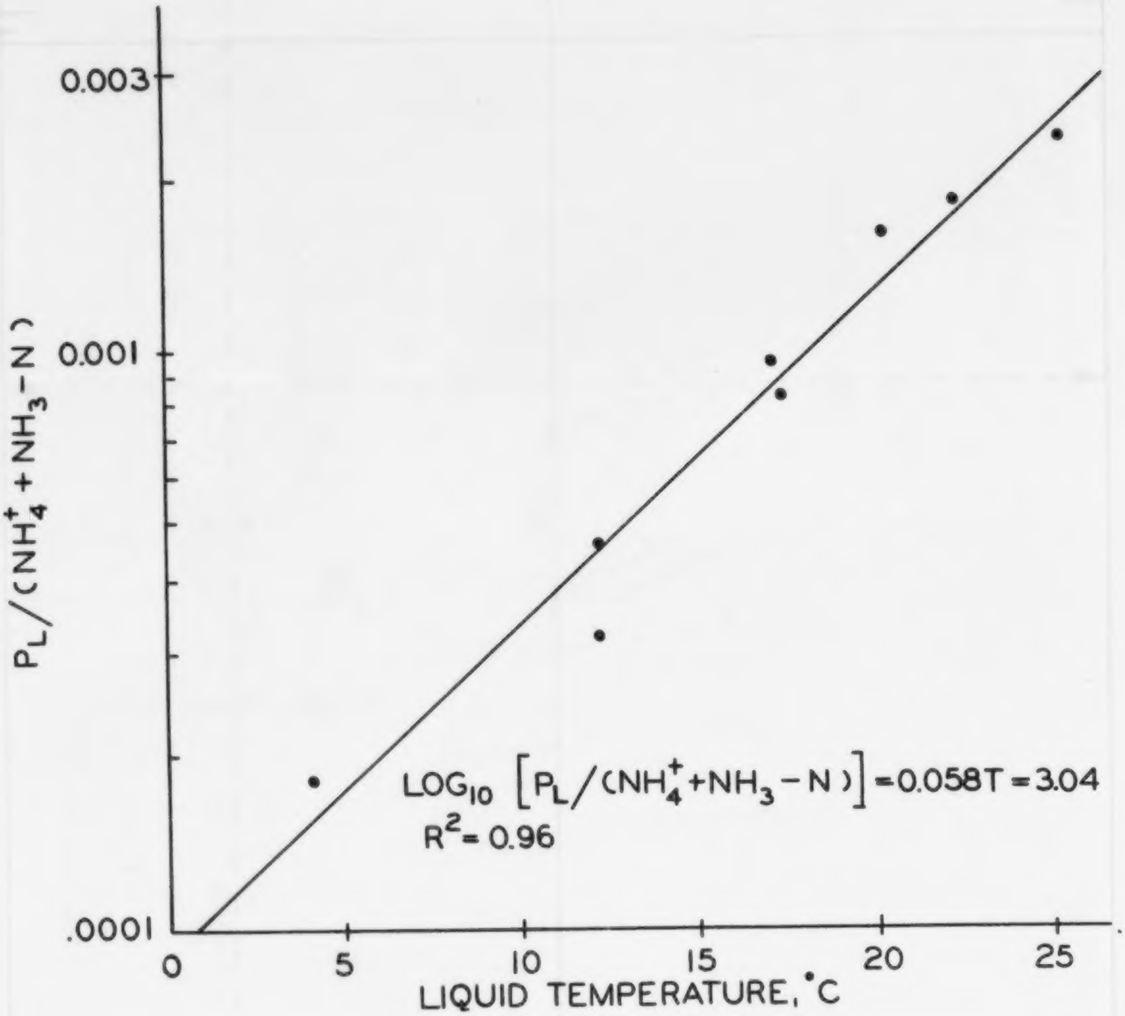

Figure 13. Relationship between partial pressure of NH_3-N gas to total NH_3-N to liquid temperature in an anaerobic swine manure lagoon (data from Koelliker and Miner, 1973).

Organic-N

$$\mathrm{RTOTN} = \mathrm{RUNOFF} \times \mathrm{NTOT}/1000 \tag{27}$$

$$\mathrm{RORGN} = \mathrm{RTOTN} \times (1 - \mathrm{FNH3}) \tag{28}$$

$$\mathrm{KA}_{\mathrm{PT}} = \mathrm{KA}_{20} \times 50.5 \times 10^{\{7.71 - 2758/(273 + \mathrm{PT})\}} \tag{29}$$

$$\begin{aligned}\mathrm{LORGNA} = {} & \mathrm{LORGNA} \times 10^{\mathrm{KA}_{\mathrm{PT}}} + (\mathrm{RORGN} \times \mathrm{A}) - \{\mathrm{LORGNA} \times \\ & \mathrm{DISVOL}/(\mathrm{DISVOL} + \mathrm{PONVOL})\} - \{(\mathrm{RORGN} \times \mathrm{A}) + \\ & \mathrm{LORGNA}\} \times \{\mathrm{DSCHRG}/(\mathrm{DSCHRG} + \mathrm{PONVOL})\} + \\ & \mathrm{SORGNL} \times (1-10^{-\mathrm{KL}_{\mathrm{PT}}})\end{aligned} \tag{30}$$

$$\begin{aligned}\mathrm{LORGNN} = {} & \mathrm{LORGNN} + (\mathrm{RORGN} \times \mathrm{B}) - \{\mathrm{LORGNN} \times \mathrm{DISVOL}/ \\ & (\mathrm{DISVOL} + \mathrm{PONVOL})\} - \{(\mathrm{RORGN} \times \mathrm{B}) + \mathrm{LORGNN}\} \times \\ & \{\mathrm{DSCHRG}/(\mathrm{DSCHRG} + \mathrm{PONVOL})\}\end{aligned} \tag{31}$$

$$\mathrm{SORGNL} = \mathrm{SORGNL} \times 10^{-\mathrm{KL}_{\mathrm{PT}}} + (\mathrm{RORGN} \times \mathrm{C}) \tag{32}$$

$$\mathrm{SORGNN} = \mathrm{SORGNN} + (\mathrm{RORGN} \times \mathrm{D}) \tag{33}$$

$$\mathrm{LORGNT} = \mathrm{LORGNA} + \mathrm{LORGNN} \tag{34}$$

$$\mathrm{PORGN} = \mathrm{LORGNT} \times 1000/\mathrm{PONVOL} \tag{35}$$

Ammonia-N

$$\mathrm{RNH3} = \mathrm{RTOTN} \times \mathrm{FNH3} \tag{36}$$

$$\mathrm{P}_{\mathrm{L}} = 10^{(0.057\,\mathrm{PT} - 4.02)} \times \mathrm{LNH3} \times 1000/\mathrm{PONVOL} \tag{37}$$

$$\begin{aligned}\mathrm{VNH3} = {} & \mathrm{Kv} \times (\mathrm{WINDD})^{0.8} \times (\mathrm{T} + 273)^{-1.4} \times \mathrm{PLSA}/ \\ & \mathrm{LTAREA} \times (\mathrm{P}_{\mathrm{L}} - 0.1)\end{aligned} \tag{38}$$

$$\begin{aligned}\mathrm{LNH3} = {} & \mathrm{LNH3} - \mathrm{VNH3} + \mathrm{RNH3} - \mathrm{LNH3} \times \{\mathrm{DISVOL}/ \\ & (\mathrm{DISVOL} + \mathrm{PONVOL})\} - \mathrm{LNH3} \times \{\mathrm{DSCHRG}/ \\ & (\mathrm{DSCHRG} + \mathrm{PONVOL})\} + \mathrm{LORGNA} \times (1-10^{-\mathrm{KA}_{\mathrm{PT}}})\end{aligned} \tag{39}$$

$$\mathrm{PNH3} = \mathrm{LNH3} \times 1000/\mathrm{PONVOL} \tag{40}$$

$$\mathrm{PTOTN} = \mathrm{PORGN} + \mathrm{PNH3} \tag{41}$$

where:

RTOTN = TKN contained in feedlot runoff, kg/ha for particular day under consideration

RORGN = Org-N contained in feedlot runoff, kg/ha for particular day under consideration

LORGNA = Org-N in liquid that can be ammonified, kg/ha

KA_{PT} = ammonification rate constant, day^{-1}

SORGNL = liquefiable Org-N in the accumulated solids, kg/ha

LORGNN = Org-N in liquid not ammonifiable, kg/ha

SORGNN = Org-N in solids that is not liquefiable, kg/ha

LORGNT = total amount of Org-N in liquid, kg/ha

PORGN = concentration of Org-N in pond liquid, mg/ℓ

RNH3 = NH_3-N contained in feedlot runoff, kg/ha for particular day under consideration

LNH3 = NH_3-N in liquid, kg/ha

VNH3 = amount of NH_3-N volatilized from the liquid surface, kg/ha

WINDD = average monthly windrun, km/day at feedlot location

PLSA = surface area of retention pond liquid on a particular day, m^2

LTAREA = surface area of feedlot, ha

PNH3 = concentration of NH_3-N in pond liquid, mg/ℓ

PTOTN = concentration of TKN in pond liquid, mg/ℓ

Example

Day when pond has 1140 m^2 of PLSA surface area/ha of lot surface:

LNH3 = 200 kg/ha of lot
PONVOL = 2000 m^3/ha of lot
100 mg/ℓ of $(NH_3 + NH_4^+) - N$

PT = 25 pond liquid temperature, $^{\circ}C$

TO = 25 average air temperature, °C

WINDD = 193 km /day

$P_L = 10^{(0.058(25) - 3.04)} \times 200 \times 1000/2000$

$P_L = 2.57$

$VNH3 = 2.53 \times 10^{-2} \frac{5000}{I} (120)^{0.8} (298)^{-1.4} (2.57 - 1)$

$\frac{Kg}{day\text{-}ha\ of\ lot}$

$VNH3 = 3.14 \frac{Kg}{day\text{-}ha} \simeq 1.5\%$ of NH3 present day

PHOSPHORUS

The Total-P in a runoff retention pond should follow patterns similar to that in an anaerobic lagoon. A portion of the Total-P is contained in the organic fraction in the waste as organic-P (Org-P) and a portion will be in true solution as inorganic-P (Inorg-P). The fraction contained as Org-P will be related to the measure of the organic strength of the material, COD. There probably is not a simple relationship between COD and Org-P, however, because the relative content of P to the COD will likely decrease as the organic material is broken down or decreases. The apparent reason for this fact is that the organic compounds containing P are likely to be more easily degraded than those of the more resistant materials that also exert a COD.

The amount of Inorg-P is a function of the solubility of Inorg-P containing compounds such as calcium phosphate $[CO_3 (PO_4)_2]$ and magnesium ammonium phosphate $(Mg\ NH_4\ PO_4)$. Also, the amount of stirring or mixing in the lagoon that could bring precipitated inorganic compounds from the sludge layer into solution will also have an effect upon the Total-P in the solution. Studies of an anaerobic lagoon have shown that as the temperature and pH increase, the Total-P in solution decreases similar to the NH_3-N but at a slower rate. It is likely that the solubility of Inorg-P containing compounds is decreased as the ph increases above ph 7.

Of the data available on the P content of feedlot runoff or that contained in the runoff retention basin, there is little information to discern the relative amounts of Org- and Inorg-P. Also, the form of P that is discharged in an overflow from the basin or delivered to the runoff disposal area is not likely to be of major concern. Therefore, in this model the P content will be reported only as Total-P. It is recognized that two components are in existence, however, it is beyond the scope of this development or of initial data collection to separate the components and identify the relationships that might exist in determining the relative amounts of each type of P.

Data from Dickey and Vanderholm (1976) and included herein as Figures 7 and 8 show that the Total-P in a beef feedlot runoff retention pond reached a maximum of slightly over 100 mg/ℓ. Data from Hamilton Standard Corporation (1973) show an average Total-P in feedlot runoff from a dirt lot of 92 mg/ℓ. Manges, et al. (1975) showed that the Total-P in feedlot runoff could be correlated to the COD in the runoff although the correlation was quite low ($r = 0.64$). Comparison of the COD and Total-P for runoff retention pond liquid reported by Dickey and Vanderholm (1976) and included herein in Figures 5 and 7 show the same direction of increasing or decreasing concentrations of COD and Total-P with time. From these data it is possible to develop a relationship between Total-P and COD. The trend is in the same general direction, however, there does not appear to be a simple linear relationship between concentrations of Total-P and COD. A least square linear regression of

$$\text{Total-P} = m(\log_{10}\text{COD}) + b \tag{42}$$

resulted in an $r = 0.67$.

A careful look at the NH_3-N in the liquid and Total-P in the liquid for data from Dickey and Vanderholm (1976) and contained herein in Figures 4 and 7 show there might be a better relationship between these two constituents. The apparent reason for this fact would be that as the temperature of the liquid rises, so does the pH of the liquid. Increasing the pH and temperature likely decreases the solubility of Inorg-P containing compounds in a liquid. Couple with this fact the effect of increasing temperatures upon the breakdown of COD in the liquid which would release much of the previously Org-P into solution as Inorg-P. The result of these activities would be that the maximum amount of Total-P in solution would decrease as the temperature increases. Values of Total-P and NH_3-N for the sampling dates during 1974 from the previously cited data were plotted in Figure 14. From this plot a least squares linear regression line of best fit revealed that

$$\text{Total-P} = .33 \times (NH_3\text{-N}) + 24.4, \tag{43}$$

with $r = 0.86$. The correlation coefficient for this relationship is considerably superior to that for Total-P related to COD. Therefore, this relationship will be used to estimate the maximum amount of Total-P one would expect to find in the liquid in the runoff retention pond.

To model Total-P in the retention pond, a scheme similar to that shown in Figure 15 will be followed. All of the Total-P in the runoff entering the pond will assume to go initially into

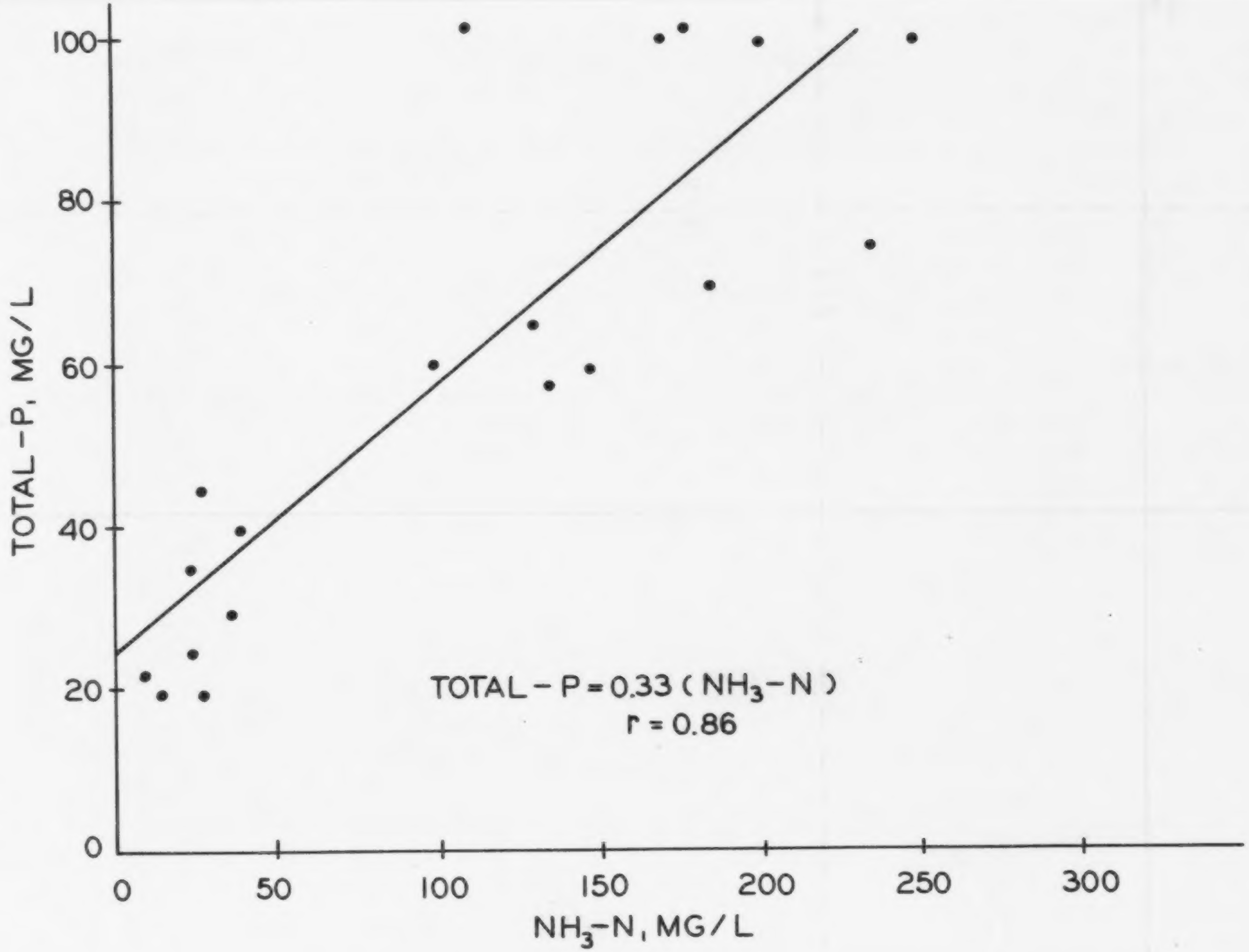

Figure 14. Relationship between Total-P and NH$_3$-N in a holding pond for beef. Data from Dickey and Vanderholm (1976).

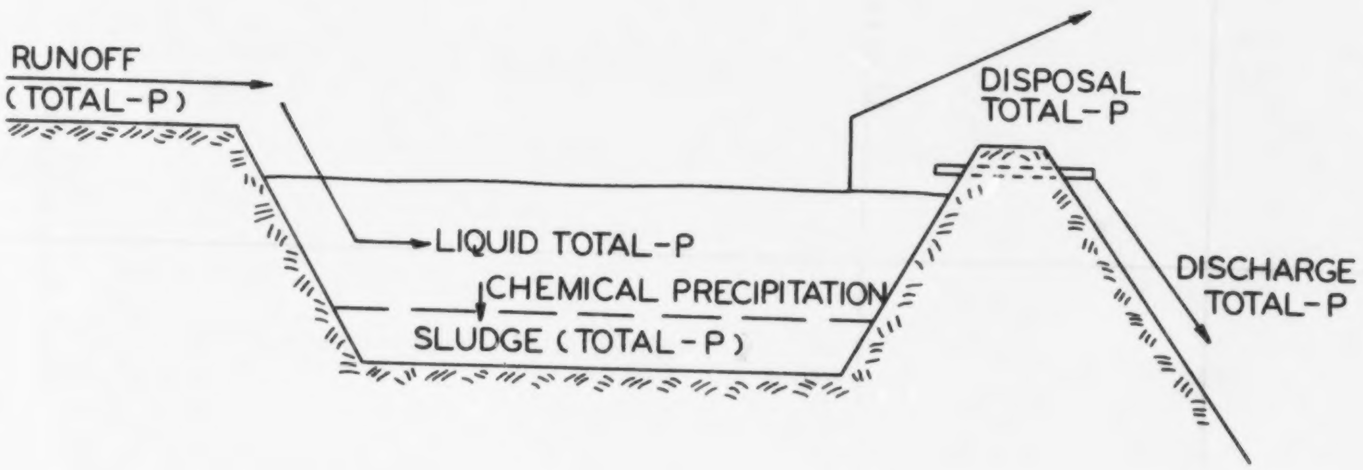
RUNOFF
(TOTAL-P)
LIQUID TOTAL-P
CHEMICAL PRECIPITATION
SLUDGE (TOTAL-P)
DISPOSAL
TOTAL-P
DISCHARGE
TOTAL-P

Figure 15. Total-P accounting for feedlot runoff retention pond.

the liquid in the pond. The maximum amount of Total-P that can remain in solution will be determined from the above relationship between NH_3-N and Total-P. If the Total-P in the liquid is greater than that estimated that the liquid can in fact hold at maximum concentration, the excess P above that amount will precipitate chemically and settle into the sludge. The amount of Total-P in solution then will be reduced by the amount so precipitated. If the concentration of Total-P in the liquid is less than the maximum amount it can hold, all of the Total-P will remain in solution. It will be assumed that none of the Total-P precipitated into the sludge will redissolve into the liquid. Once into the sludge the precipitated Total-P will remain there until the sludge or solids are removed. The amount of Total-P removed in liquid by either disposal or direct discharge will be determined by the amount of liquid removed by either route times the concentration of Total-P in that liquid.

The equations for estimation of P are shown below.

PTOTP = TOTP x 1000/PONVOL (44)

RTOTP = P x RUNOFF/1000 (45)

TOTP =(TOTP + RTOTP)- TOTP x DISVOL/(PONVOL + DISVOL) - TOTP x DSCHRG/(DSCHRG + PONVOL) - PRECP (46)

PTOTPM = 0.33 x PNH3 + 24.4 (47)

IF (PTOTPM.GT.120) PTOTPM = 120 (48)

PRECP = (PTOTP - PTOTPM) x PONVOL/1000 (49)

PRECPT = PRECPT + PRECP (50)

PTOTP = PTOTPM (51)

DCHGPT = DCHGPT + (TOTP x DSCHRG)/(DSCHRG + PONVOL) (52)

DISPT = DISPT + (TOTP x DISVOL)/(DISVOL + PONVOL) (53)

where:

RTOTP = Total-P contained in feedlot runoff, kg/ha for particular day under consideration

TOTP = Total-P in liquid, kg/ha

PRECP = Total-P that is precipitated from the liquid into the sludge for particular day under consideration, kg/ha

PRECPT = total amount of Total-P that has accumulated in the sludge, kg/ha

PTOTP = concentration of Total-P in liquid, mg/ℓ

PTOTPM = maximum solubility of Total-P in liquid, mg/ℓ for particular day under consideration

DISPT = total amount of Total-P removed in liquid for disposal, kg/ha

DCHGPT = total amount of Total-P lost in liquid from discharges, kg/ha

SOLIDS

Solids entering the runoff retention pond will assume to be FDS and TVS. The sum of these two will be the TS considered in this model. TVS can usually be related to the organic strength of the liquid, in this case, measured as COD. Therefore, the TVS in the runoff retention pond liquid will be equal to 1.1 times the COD of the liquid.

FDS are solids that are truly in solution. Such materials as soil particles and other settleable solids are not considered. Some FDS, especially calcium and magnesium compounds and those that contain phosphates, will precipitate from the liquid if sufficient concentrations are reached. Also, FDS are lost when NH_3-N volatilizes into the atmosphere. However, loss of NH_3-N will also occur during the analyses for FDS. Therefore, that loss will not be considered in the model. The precipitation of solids into the sludge layer in retention ponds is a complex chemical process that is not completely understood. Precipitation of phosphate containing compounds is one of the major sources of loss of P from the liquid in anaerobic lagoons. For this model, it is assumed that the phosphate materials precipitate as $CO_3(PO_4)_2$ one compound with a rather low solubility. When the Total-P in solution exceeds the maximum predicted by the Total-P portion of the model and precipitation occurs, it will be assumed that the FDS are reduced by a factor of seven times the amount of Total-P that is precipitated. Seven is approximately the ratio of the P to the total molecular weight of $CO_3(PO_4)_2$. Otherwise, the FDS concentration will change due to evaporation from and precipitation onto the pond and from additions by runoff from the feedlot surface (Figure 16).

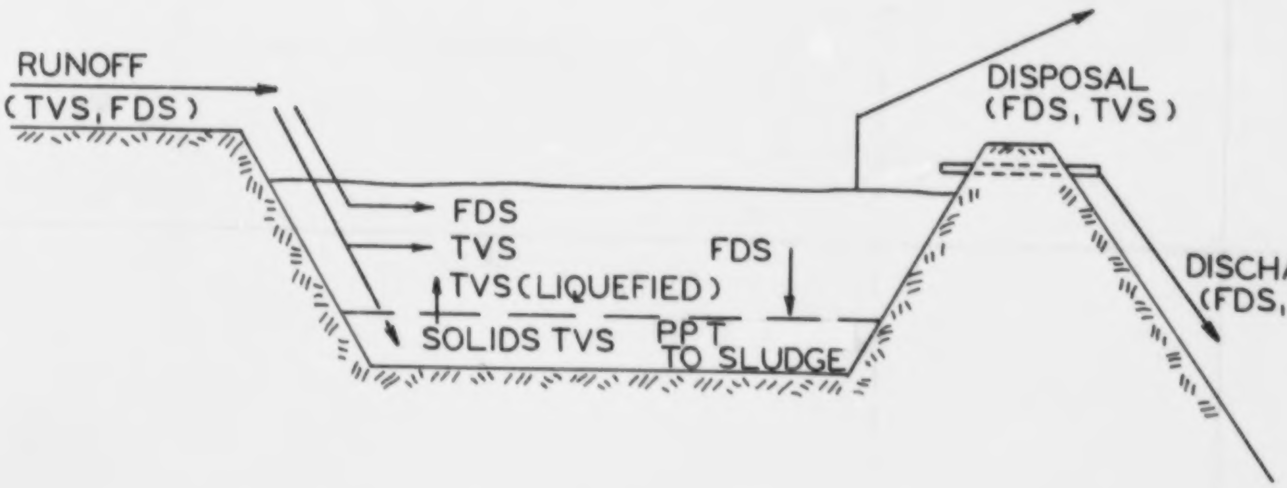
RUNOFF
(TVS, FDS)
DISPOSAL
(FDS, TVS)
FDS
TVS
TVS (LIQUEFIED)
FDS
SOLIDS TVS
PPT
TO SLUDGE
DISCHARGE
(FDS, TVS)

Figure 16. TVS and FDS accounting for feedlot runoff retention pond.

The TS in the retention pond liquid will then be the sum of the FDS plus the TVS. Each fraction will be determined separately and then the two added to estimate TS.

$$PFDS = LFDS \times 1000/PONVOL \qquad (54)$$

$$LFDS = LFDS + RFDS - (PRECP \times 7) - \{LFDS \times DISVOL/(DISVOL + PONVOL)\} - \{LFDS \times DSCHRG/(DSCHRG + PONVOL)\} \qquad (55)$$

$$RFDS = FDS \times RUNOFF/1000 \qquad (56)$$

$$LTVS = LCODT \times 1.1 \qquad (57)$$

$$PTVS = LTVS \times 1000/PONVOL \qquad (58)$$

$$PTS = PFDS + PTVS \qquad (59)$$

where:

RFDS = Total-FDS in feedlot runoff, kg/ha for particular day under consideration

FDS = FDS concentration in runoff, mg/ℓ

LFDS = Total-FDS in the retention pond liquid, kg/ha

PFDS = concentration of FDS in retention pond liquid, mg/ℓ

LTVS = TVS in retention pond liquid, kg/ha

PTVS = concentration of TVS in retention pond liquid, mg/ℓ

PTS = concentration of TS in retention pond liquid, mg/ℓ

INDICATOR ORGANISMS

TC, FC and FS bacteria counts in the retention pond were assumed to decay exponentially, following runoff from a rainfall event. The coliform decay rates were assumed to be temperature dependent and to have the following forms:

$$TCOLI = TCOLI\ (1-10^{KFTC_{PT}}) + RTCOLI\ \left(\frac{RUNOFF}{PONVOL + DISVOL + DSCHRG}\right) \qquad (60)$$

$$FCOLI = FCOLI\ (1-10^{KFTC_{PT}}) + RFCOLI\ \left(\frac{RUNOFF}{PONVOL + DISVOL + DSCHRG}\right) \qquad (61)$$

$$\mathrm{FSTRP} = \mathrm{FSTRP}\ (1-10^{\mathrm{KFS20}}) + \mathrm{RFSTRP}\ \left(\frac{\mathrm{RUNOFF}}{\mathrm{PONVOL} + \mathrm{DISVOL} + \mathrm{DSCHRG}}\right) \quad (62)$$

$$\mathrm{KFTC}_{\mathrm{PT}} = \mathrm{KFTC}_{20} + 0.0075\ (\mathrm{PT} - 20) \quad (63)$$

$$\mathrm{KFS}_{\mathrm{PT}} = \mathrm{KFS}_{20} + 0.0075\ (\mathrm{PT} - 20) \quad (64)$$

where:

TCOLI = TC concentration in the retention basin, number per 100 ml

FCOLI = FC concentration in the retention basin, number per 100 ml

FSTRP = FS concentration in the retention basin, number per 100 ml

KFTC = decay rate for TC and FC, day^{-1}

KFTC_{20} = decay rate for TC and FC at 20°C

PT = Pond temperature, °C

$= \sum_{c=1}^{10} T_i/10$

T_i = average air temperature °C, for i^{th} day prior to day in question

KFS = decay rate for FS, day^{-1}

KFS_{20} = decay rate for FS at 20°C

RTCOLI = TC concentration, number per 100 ml, in feedlot runoff for the day under consideration

RFCOLI = FC concentration, number per 100 ml, in feedlot runoff for the day under consideration

RFSTRP = FS concentration, number per 100 ml, in feedlot runoff for the day under consideration

SECTION 7

FIELD SAMPLING PROGRAM FOR DATA COLLECTION

Selection of the ideal feedlot site from which to collect field data for our model was based on identifying one that would be representative of typical conditions that might be encountered in the major feeding areas of the U.S. In addition, we wanted a site that would insure us of several runoff events and disposal from the retention pond during the period. As much variation in pond volume and water quality as possible was desired so that our model would be responsive to such changes. Since our sampling program was operated during the spring and summer, we chose a more humid region of the country where rainfall was likely to be more consistent and disposal would be required. Dickey and Vanderholm (1976) had operated a sampling program at several locations in Illinois, so we felt one of those feedlots would be a suitable choice. Additionally, their previous data was available in a form that could be used to help evaluate our model's performance. Their expertise was also available to give us advice and assistance in operating the sampling program.

The feedlot used was located at the Vernon Veatch farm near Roberts, Illinois. It is about 130 km (80 miles) south-southwest of Chicago. The concrete surfaced feedlot consists of 0.32 ha (0.8 ac) of concrete with a fenceline bunk and open front sheds for shelter. Feedlot runoff from this area drains through a settling basin and into the retention pond as shown in Figure 17. Along one side about 15 m (50 ft) from the edge of the retention pond water surface is a concrete apron onto which manure accumulates from a 122 m (400 ft) long total confinement beef building. The area between the apron and holding pond is mostly grass. This building has a capacity of 400 head. Manure is worked down a sloping floor to the concrete apron where it accumulated and subsequently removed for field disposal. Runoff from extremely heavy rains that fall on the accumulated manure on the apron could flow into the runoff retention pond. During unusually wet periods accumulated runoff in the retention pond could partially inundate accumulated manure on the apron. However, such conditions would be extremely unusual and were not encountered during this study. Under most conditions, little runoff is generated from the accumulated manure on the apron and it must flow through the grassed area before reaching the pond. A third beef feeding area at the farm consisted of approximately

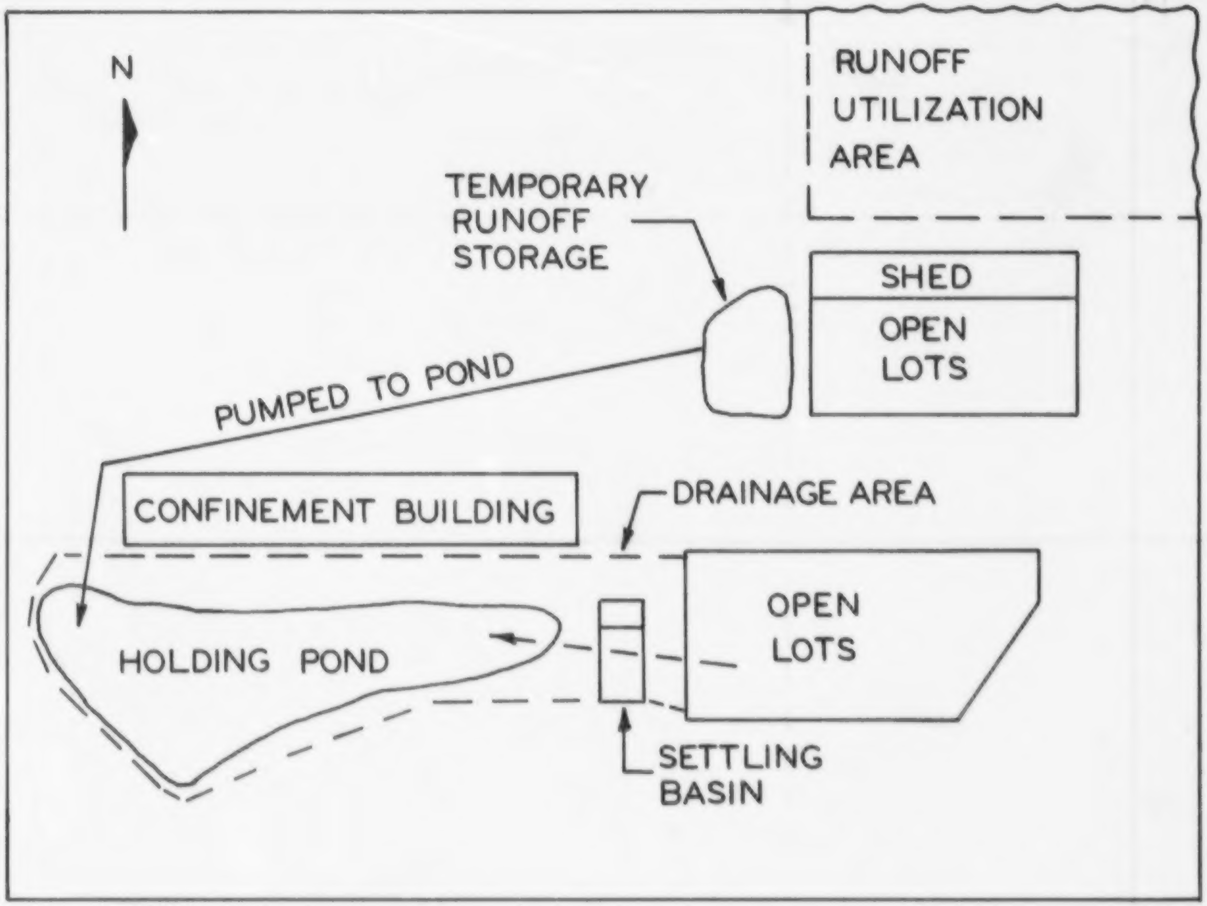
N
RUNOFF
UTILIZATION
AREA
TEMPORARY
RUNOFF
STORAGE
SHED
OPEN
LOTS
PUMPED TO POND
CONFINEMENT BUILDING
DRAINAGE AREA
OPEN
LOTS
HOLDING POND
SETTLING
BASIN

Figure 17. Layout of feedlot and runoff control system at the field site.

0.2 ha (0.5 ac) of open lot with concrete aprons around the feed bunks and some open-front shelters for the animals. Runoff from this area flowed into a small retention pond. From there it was periodically pumped into the runoff retention pond that was sampled in this study. The volume pumped was measured.

The total drainage area below the settling basin and including the surface area of the runoff retention pond was 0.53 ha (1.3 ac). This area included the manure collection apron for the confinement building. The remainder of the area was in grass. Vanderholm felt that the vegetated drainage area surrounding the pond contributed little runoff except during large storms. He discounted this area somewhat in estimating rainfall-runoff relationships.

For this model, the surface area of the pond was determined each day from stage-surface area relationships. All precipitation that fell on this area was, of course, contributed to the pond. The pond surface area was subtracted from the 0.53 ha (1.3 ac) drainage area and the difference was added to the 0.32 ha (0.8 ac) of feedlot surface in calculating the quantity of water entering the retention basin. The rainfall-runoff relationship for a non-surfaced lot was then applied to the total area to estimate the amount of runoff that was expected from the rainfall events during the study. This compromise somewhat underestimated the runoff from the feedlot and likely overestimated the runoff from the area surrounding the pond.

The runoff retention pond was originally constructed by building a dam across a natural drain. As a result the pond is long in length and relatively narrow. It has a relatively large surface area to volume relationship. Figure 18 shows the stage-storage curve and the stage-surface area relationship for the pond.

No sludge had been removed from the pond for the previous three years. However, probing to determine how much sludge was contained in the pond indicated that there was less than 5 cm (2 in) over the entire bottom except in the narrow upper reach approximately 30 m (100 ft) below the settling pond inlet. Sludge accumulation in the pond was relatively low due to the excellent removal characteristics of the settling basin and apparent good managment.

The settling basin consisted of a concrete bottom with three earth fill sides and was approximately 9 m (30 ft) long and 12 m (40 ft) wide. One side of the basin had a side slope of about 10 to 1 and was concreted so that conventional manure handling equipment could be used to remove accumulated solids. Outlets from the basin consisted of two, 61-cm (24-in) diameter slotted corrugated metal drainage pipes each with 15-cm (6-in) diameter

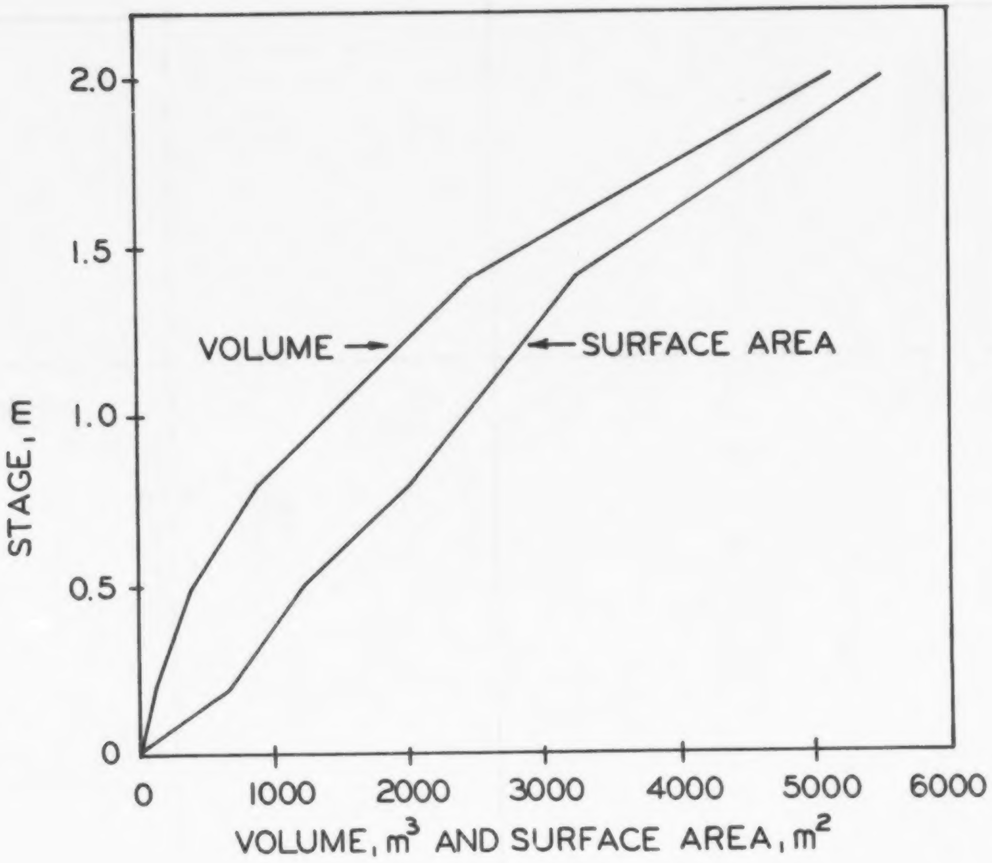

Figure 18. Stage-volume and stage-surface area relationships for runoff retention pond at field site.

PVC discharge pipe into the runoff retention pond. Excellent management at the feedlot site consistently removed the solids from the settling basin after accumulation. Operation of the settling basin probably is a critical factor affecting the quality of runoff that enters a retention pond. In this case, with timely removal of the settleable material entering the settling basin, retention pond water quality may have been better than that expected at many locations.

Disposal from the runoff retention pond was done primarily to promote crop production on adjacent land. Normally, runoff disposal was practiced in early to mid-July to apply water and nutrients to a forage crop. After the forage crop has been harvested in the fall, the pond is again pumped down to a low level by application of runoff onto the forage stubble ground. Application is done to provide adequate N for the growing crop or for the crop to be planted in the spring following fall application. Disposal during the spring is done only if there has been a large accumulation of runoff during the winter to a level that is considered a hazard by the operator.

The pond was designed to hold the runoff from six months of rainfall at this location. This volume is about 380 mm (15 in) of runoff from the drainage area of the pond. At maximum capacity, the pond will hold slightly over 5000 m^3 (50 ac-in).

DATA COLLECTION AND ANALYSIS PROCEDURES

Persons that normally worked on the farm and at the feedlot site collected the field data. Observations of minimum and maximum air temperature, amount and time of precipitation, volume of runoff removed from the retention pond, and volume of runoff added to the retention pond, staff gage reading, and any comments about operations at the feedlot were recorded each day. Generally, samples from the runoff retention pond were collected in the late afternoon. A sampling device, similar to that described by Mitchell and Dickey (1973) was used to obtain samples of the retention pond contents. Sampling was done at the lower end of the pond near where liquid was removed for disposal or would discharge if overflow had occurred and was judged to be most representative of stored runoff. A quart bottle was filled at four different locations in the lower one-fourth of the pond. Samples were collected approximately 40 cm (16 in) below the water surface. All four samples were poured into a 4 ℓ container and immediately returned to the sample preparation area at the feedlot site. Sampling was done daily from May 4 through July 31 and weekly during August through October.

As soon as the composite sample reached the preparation center, the pH and temperature of the liquid were determined to within ±0.1 pH units and $\pm 1^{\circ}$C. The sample was then thoroughly mixed by rolling the container several times. Two 500 ml bottles were then filled with portions of the mixture for chemical analysis. To the sample to be analyzed for COD, NH_3-N, and TKN, 0.8 ml of concentrated sulfuric acid was added. Both samples were then placed in a refrigerator and stored at 4°C. If that sample was also to be analyzed for bacteriological parameters, a 300-ml bottle was also filled and placed in the refrigerator at 4°C.

Samples for chemical analysis were shipped to the Agricultural Engineering Department at Corvallis twice weekly. The refrigerated samples were placed in a foam insulated chest with an additional 5 cm (2 in) of styrofoam insulation on all sides of the samples. The samples along with three to four kg (six to eight lb) of "blue ice" were placed in the chest and the chest was closed and taped. The samples were shipped via Air United Parcel Service, which consistently delivered samples to Corvallis within four days after shipment. Upon arrival at the laboratory, the samples were within 2°C of 4°C. Chemical analyses were begun immediately upon receipt. Usually samples were analyzed less than seven days after collection. All chemical analyses were done in accordance with procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1976).

Samples for bacteriological determinations were allowed to cool over night and then were packed in an ice chest along with 1.5 kg (3 lb) of "blue ice" and shipped via United Parcel Service to a laboratory located about 85 km (50 miles) from the feedlot. Samples were usually delivered within 24 hours after shipment and always within 48 hours. All bacteriological analyses were done in accordance with procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1976), also.

SECTION 8

INCORPORATION OF FIELD DATA INTO PREDICTIVE MODEL

Occasional large discrepancies occurred between measured pond volumes and volumes predicted by the hydrologic model. The nature of these discrepancies indicated that substantial subsurface seepage was entering the pond, possibly originating in cultivated fields adjacent to the feedlot. These spurious flows rendered much of the data unusable. As a consequence, only data collected during a single 45 day period was considered sufficiently reliable to be used in calibration of the model. The accepted procedure for a modeling effort of this sort calls for calibrating the model with one set of data and then testing with a second set of data. However, because of the subsurface flow problem the data collected were not sufficient for an independent test of the model. The model was simply calibrated.

The preceeding sections of this paper have presented the model in a completely general form, with the coefficients of the various equations left unspecified. Table 5 includes the coefficient values which were chosen, initially, on the basis of previous research. During calibration of the model several of these coefficients were revised. The revised values are also shown in Table 5.

The observed rate of decomposition of COD was substantially greater than predicted. KC_{20} was increased from 0.015 to 0.045 to account for this. Predicted concentrations of Org-N were lower than observed concentrations immediately after a runoff event. Baseline N concentration was therefore increased from 400 to 800 mg/ℓ.

Predicted NH_3-N concentrations were substantially lower than observed values. To compensate for this, three coefficient changes were made. The ammonification rate constant (KA20) was increased from .015 to .055, the volatilization constant (Kv) was reduced from 2.53 to 1.25, and the baseline NH_3-N fraction in runoff (K_{FRAC}) was increased from 0.2 to 0.4.

Four of the constants used in prediction of bacteria counts were altered considerably, reflecting the difficulty of estimating

TABLE 5. MODEL COEFFICIENTS

Parameter	Initially Assumed Value	Final Calibration Value
COD_{BASE}	4200	4200
N_{BASE}	400	800
P_{BASE}	75	75
FDS_{BASE}	5000	5000
TVS_{BASE}	4600	4600
TC_{BASE}	75×10^6	8×10^6
FC_{BASE}	35×10^6	8×10^6
FS_{BASE}	25×10^6	7×10^6
K_{FRAC}	0.2	0.4
$KLPT_{20}$	.005	.005
KC_{20}	.015	.045
KA_{20}	.015	.055
Kv	2.53×10^{-2}	1.25×10^{-2}
$KFTF_{20}$	-0.60	-0.8
$KFTC_{20}$	-0.60	-0.8
KFS_{20}	-0.78	-0.9
A	0.24	0.24
B	0.36	0.36
C	0.28	0.28
D	0.12	0.12

bacterial counts with a general model. These are shown in Table 5 as changes in $KFTF_{20}$, $KFTC_{20}$, TC_{BASE} and FC_{BASE}.

No other changes were made in model coefficients. However, it was observed that P concentrations appeared to be limited at times by factors not accounted for by consideration of solubility in solution.

In view of the data limitations, this calibration of the model cannot be considered to have confirmed the model nor to have adequately represented the idealized situation which was posed in the model building effort. Substantially more data would be required to do this.

Figures 19 through 24 include the concentration data for the various constituents that were measured along with a line indicating the predicted values for these constituents. The plots are based upon the final calibration values shown in Table 5.

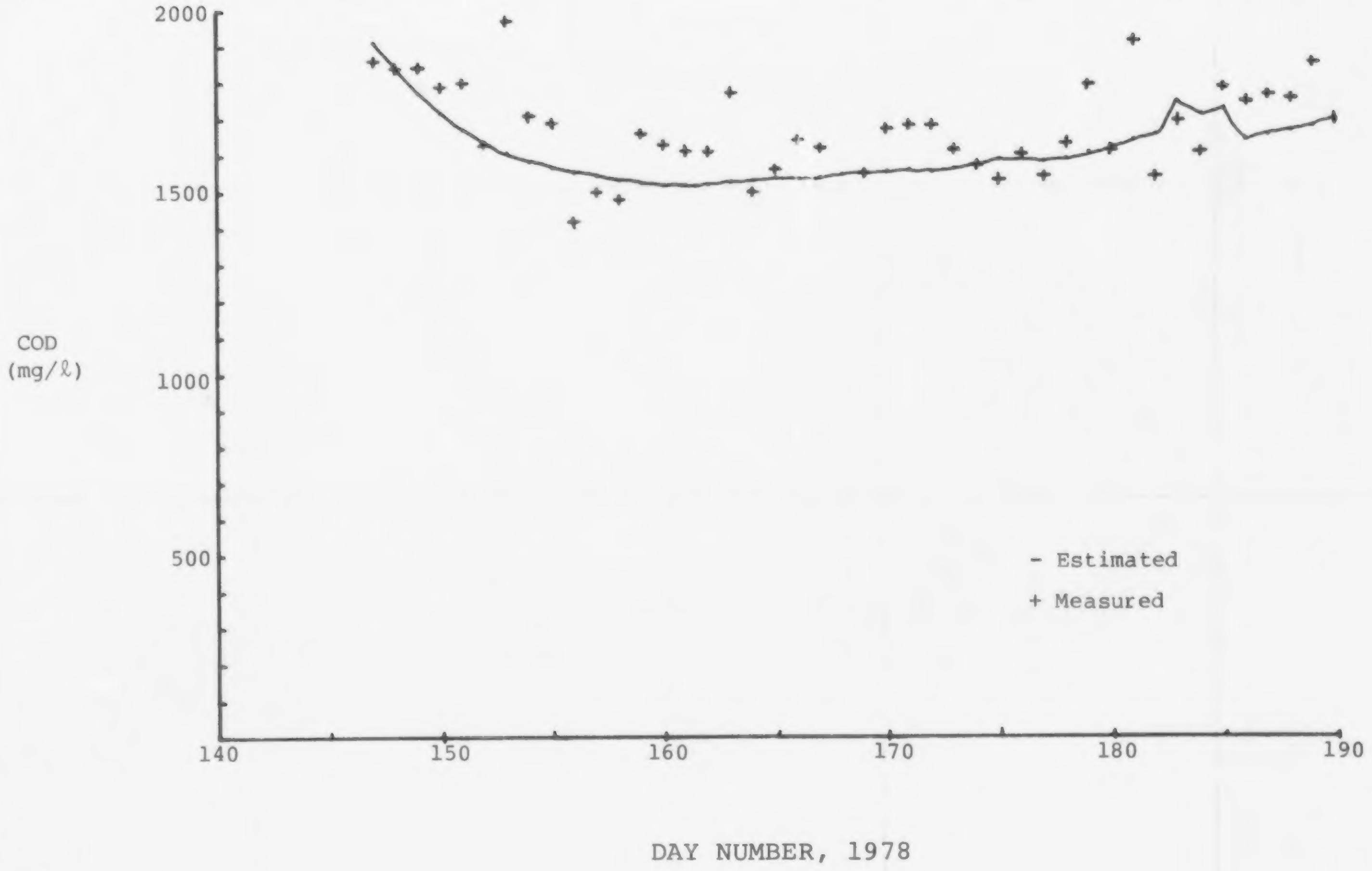

Figure 19. Measured and model predicted COD concentrations in a cattle feedlot runoff retention basin.

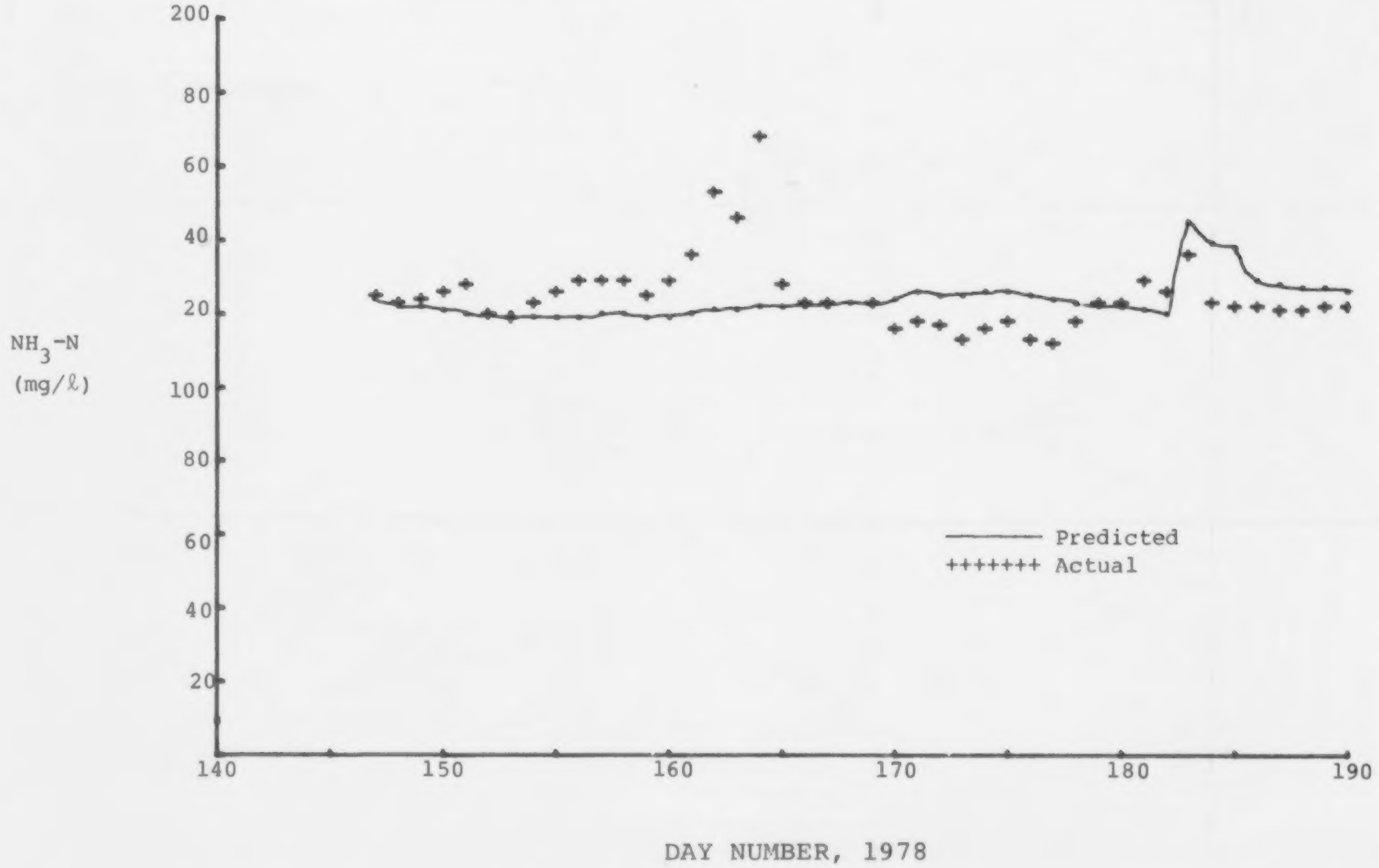

Figure 20. Measured and model predicted NH_3-N concentrations in a cattle feedlot runoff retention basin.

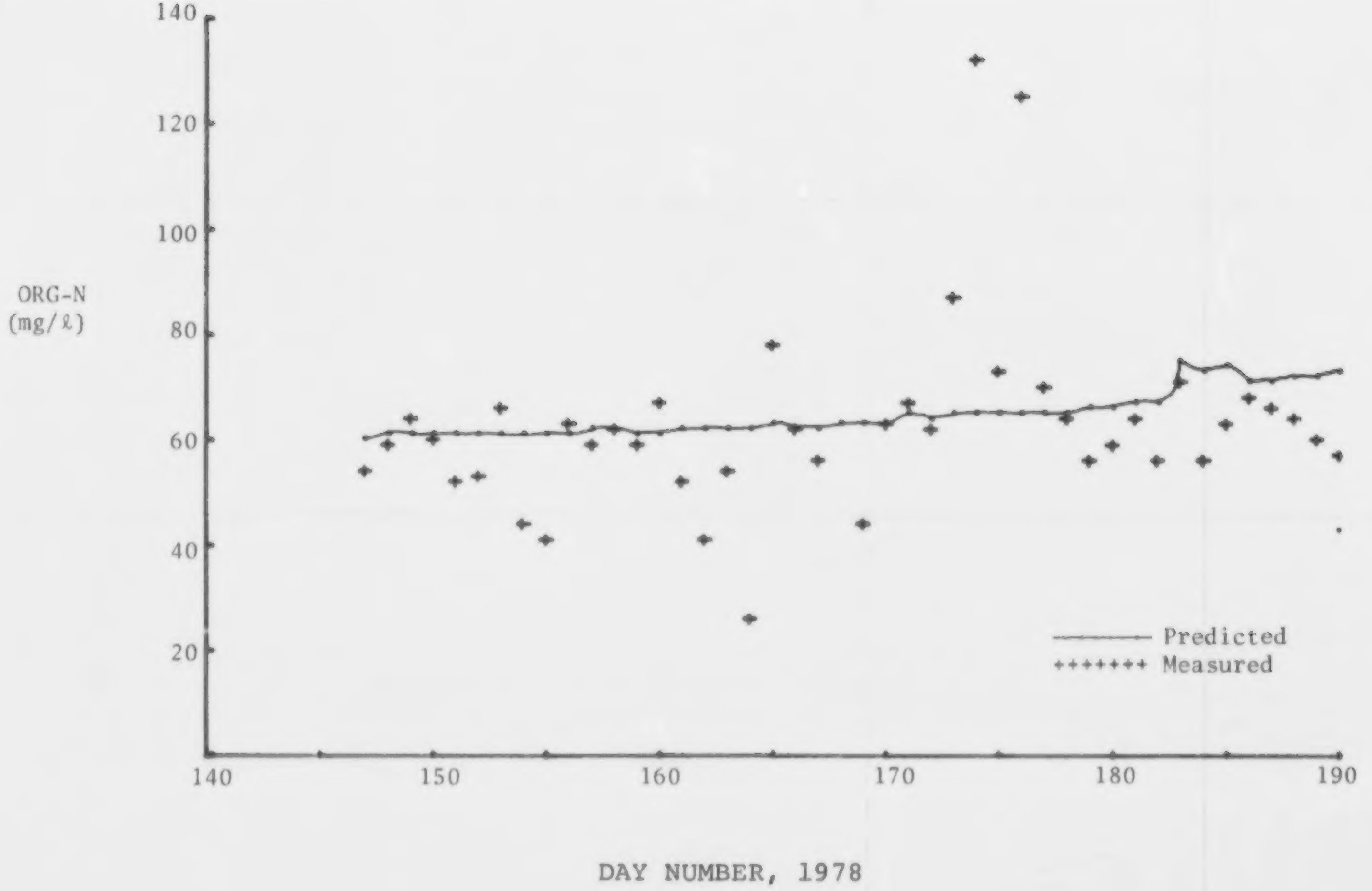

Figure 21. Measured and model predicted Org-N concentrations in a cattle feedlot runoff retention basin.

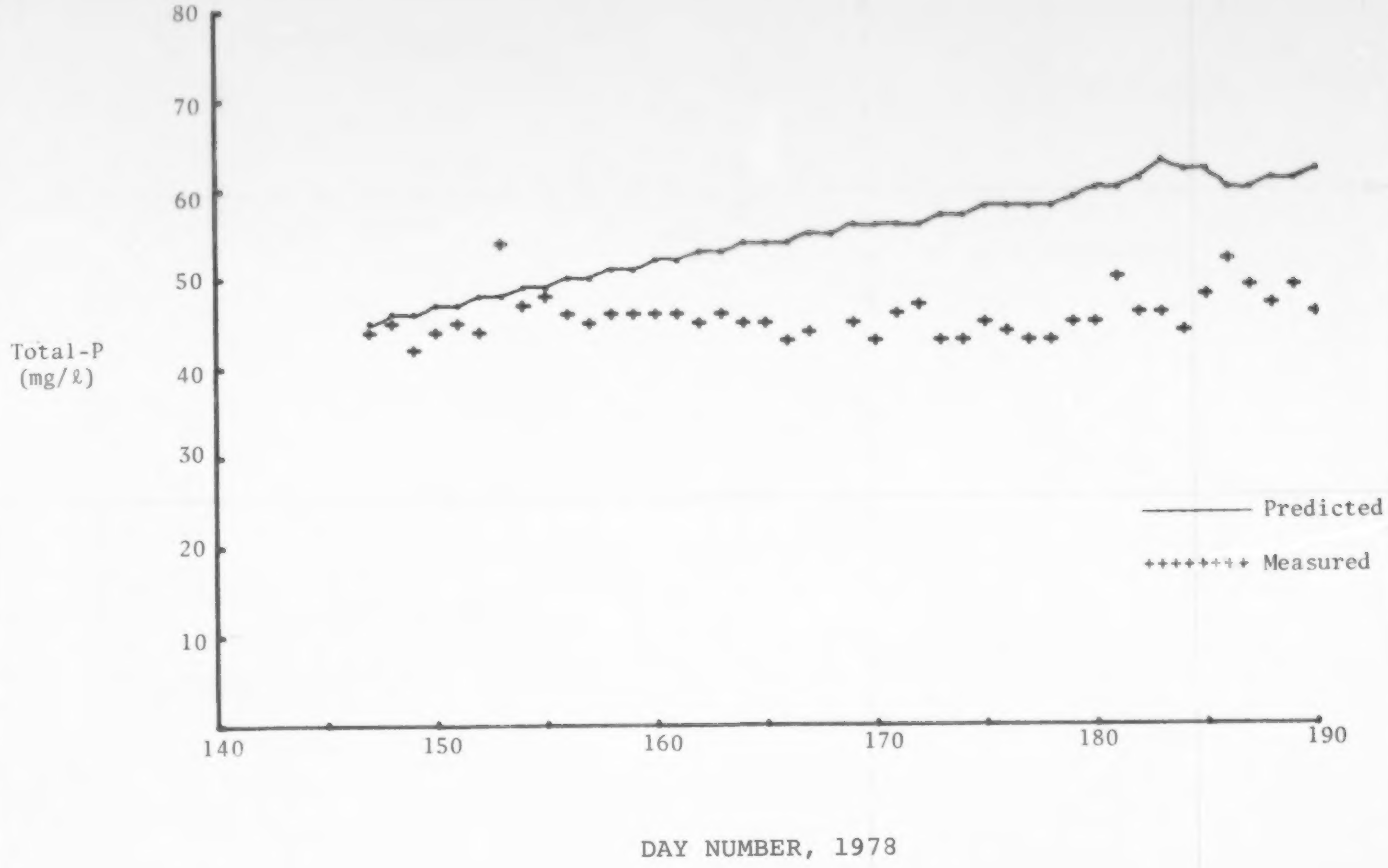

Figure 22. Measured and model predicted Total-P concentrations in a cattle feedlot runoff retention basin.

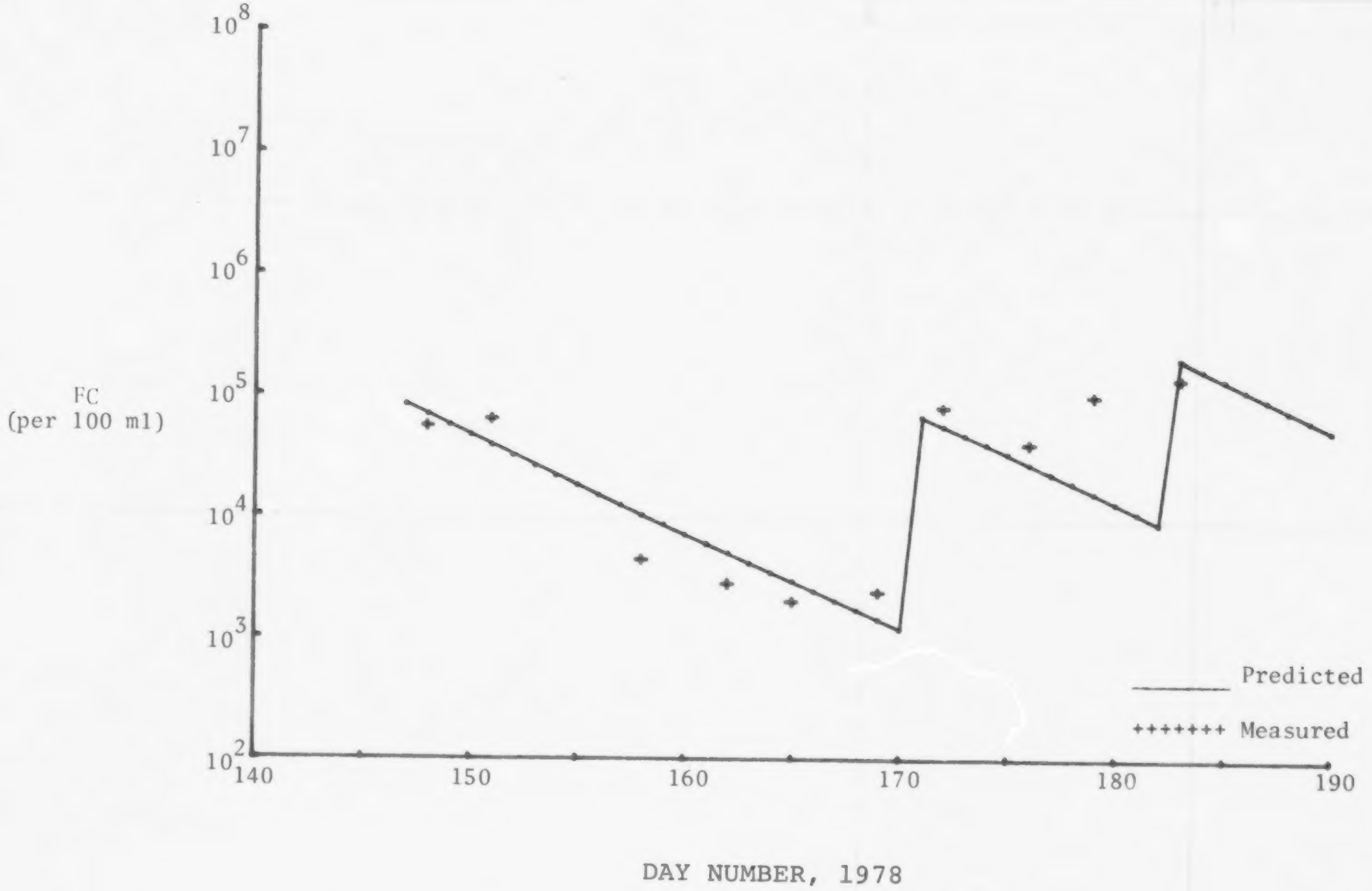

Figure 23. Measured and model predicted FC numbers per 100 ml in a cattle feedlot runoff retention basin.

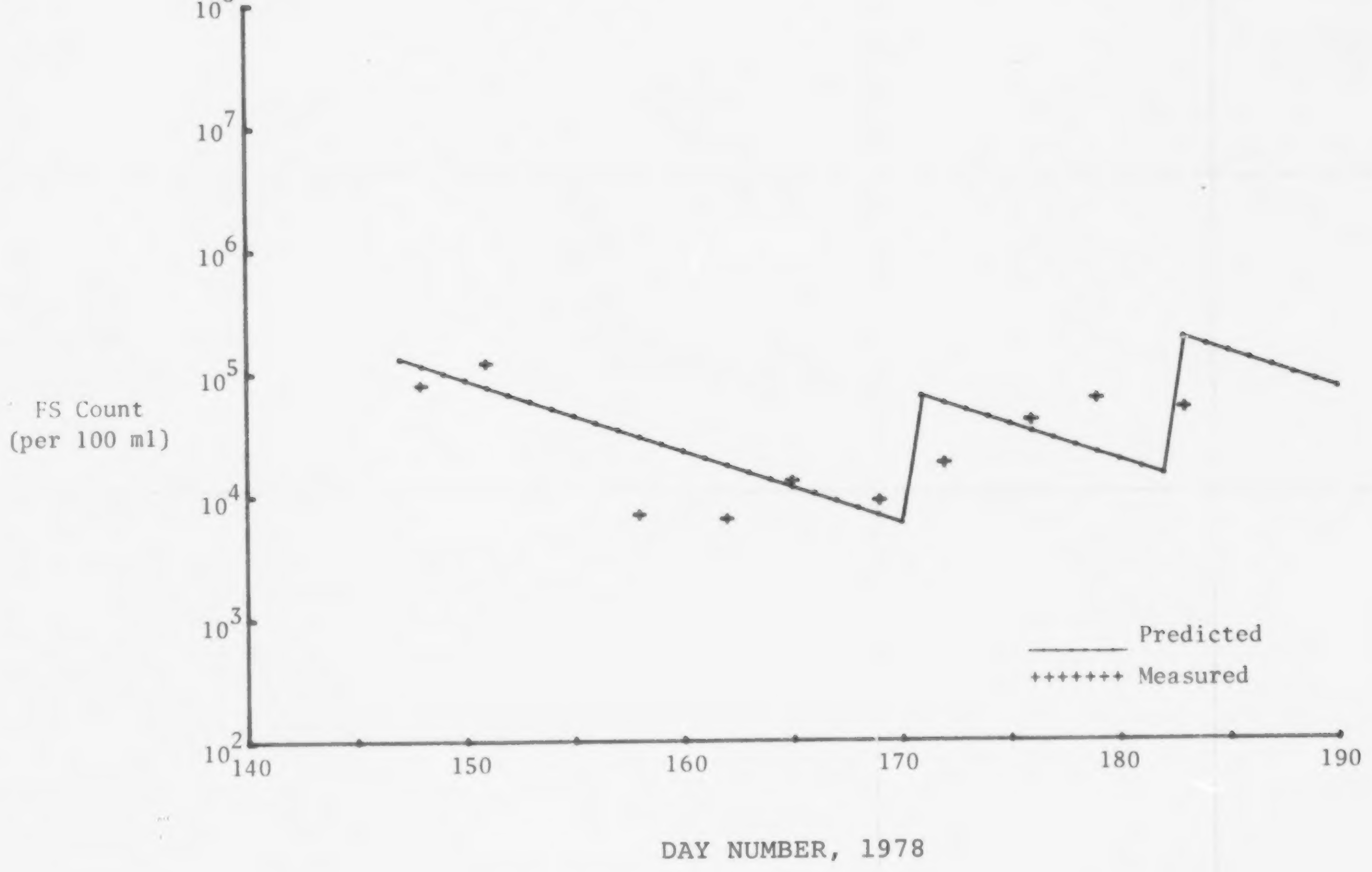

Figure 24. Measured and model predicted FS numbers per 100 ml in a cattle feedlot runoff retention basin.

SECTION 9

DEMONSTRATION OF THE MODEL

In order to demonstrate the ability of the model to predict runoff and retention basin quality a simplified weather pattern was specified in which constant monthly temperatures were assumed and discrete rainfall events were specified. From those simplifying assumptions which allow the influence of particular variables to be noted one can view the function of the model. Table 6 indicates the temperature data under which operation was assumed to occur. The feedlot was assumed to be of unit size in order to eliminate that variable from the results. A runoff retention basin having a surface area equal to 35 percent of the feedlot surface area was assumed.

TABLE 6. AVERAGE MONTHLY AIR TEMPERATURES ASSUMED TO DEMONSTRATE THE FEEDLOT RUNOFF AND RETENTION BASIN QUALITY PREDICTIVE MODEL

Month	Temperature C	F	Month	Temperature C	F
January	2	35	July	27	80
February	4	40	August	27	80
March	7	45	September	21	70
April	10	50	October	16	60
May	16	60	November	10	50
June	21	70	December	4	40

Cattle feedlot runoff quality for the various dates on which runoff was assumed to occur are shown in Tables 7 and 8. Those tables show the variations expected to occur with temperature, rainfall intensity and previous rainfall. The effect of precipitation occurring as accumulated snowfall is shown by the runoff which occurred on February 2 and 3 when no rainfall occurred. January temperatures were assumed to be sufficiently low to maintain a snowpack hence a highly concentrated runoff was noted as soon as the temperature increased. Subsequent storms of one, two and three days duration are shown for comparison purposes to note the effect of those variables on both runoff quality and quantity.

TABLE 7. PREDICTED CATTLE FEEDLOT RUNOFF COD, TKN, NH_3-N, AND P UNDER VARIOUS CONDITIONS

Date	Precip. (mm)	Avg. Temp. °C	Runoff m^3/ha	COD mg/ℓ	TKN mg/ℓ	NH_3-N mg/ℓ	P mg/ℓ
1-3*	25	2	0				
1-20*	51	2	0				
2-2†	0	4	660	10,000	1,910	175	179
2-3	25	4	109	5,170	984	95	92
3-3	25	7	107	5,800	1,100	133	104
3-4	25	7	193	5,890	1,120	140	105
3-5	25	7	193	5,930	1,130	145	106
4-3	25	10	109	6,510	1,240	188	116
4-20	51	10	422	5,040	961	153	90
5-3	25	16	127	8,000	1,520	350	143
6-3	51	21	328	7,640	1,450	530	135
6-4	51	21	427	7,870	1,500	580	140
6-5	51	21	427	6,000	1,520	609	143
7-3	25	27	107	12,700	2,420	1,400	226
8-3	51	27	381	10,000	1,920	1,222	180
8-20	102	27	823	7,630	1,450	921	136
10-3	25	16	137	8,780	1,670	463	157
10-4	25	16	226	8,510	1,620	422	152
10-5	25	16	226	8,380	1,600	403	150

* Represents snowfall which was accumulated on the lot surface.

† Represents runoff due to the melting of accumulated snow.

TABLE 8. PREDICTED CONCENTRATION OF INDICATOR MICROORGANISMS IN CATTLE FEEDLOT RUNOFF

Date	TC	FC	FS
	millions of bacteria per 100 ml		
2-2	46.4	23.2	580
2-3	22.2	11.1	277
3-3	17.2	8.5	214
3-4	16.6	8.3	207
3-5	16.3	8.1	204
4-3	13.3	6.6	166
4-20	9.6	4.8	120
5-3	8.4	4.2	105
6-3	3.8	1.9	48
6-4	3.6	1.8	45
6-5	3.4	1.7	43
7-3	3.0	1.5	37
8-3	2.1	1.0	26
8-20	1.6	0.8	19
10-3	6.8	3.4	85
10-4	7.3	3.7	91
10-5	7.6	3.8	95

Runoff retention basin quantity and quality are shown in Figures 25 through 29. These figures show the impact that various runoff events have on the pond liquid concentrations. In all cases the pond is assumed to have a completely mixed liquid layer overlying a sludge layer. Thus, a runoff event has an immediate effect upon the liquid concentration. The periods during which various constituents increased when no runoff was occurring reflects the degradation of the sludge layer releasing soluble materials into the liquid portion. Again, the model allows one to view the impact of temperature and precipitation on the rate of change of various constituents with time.

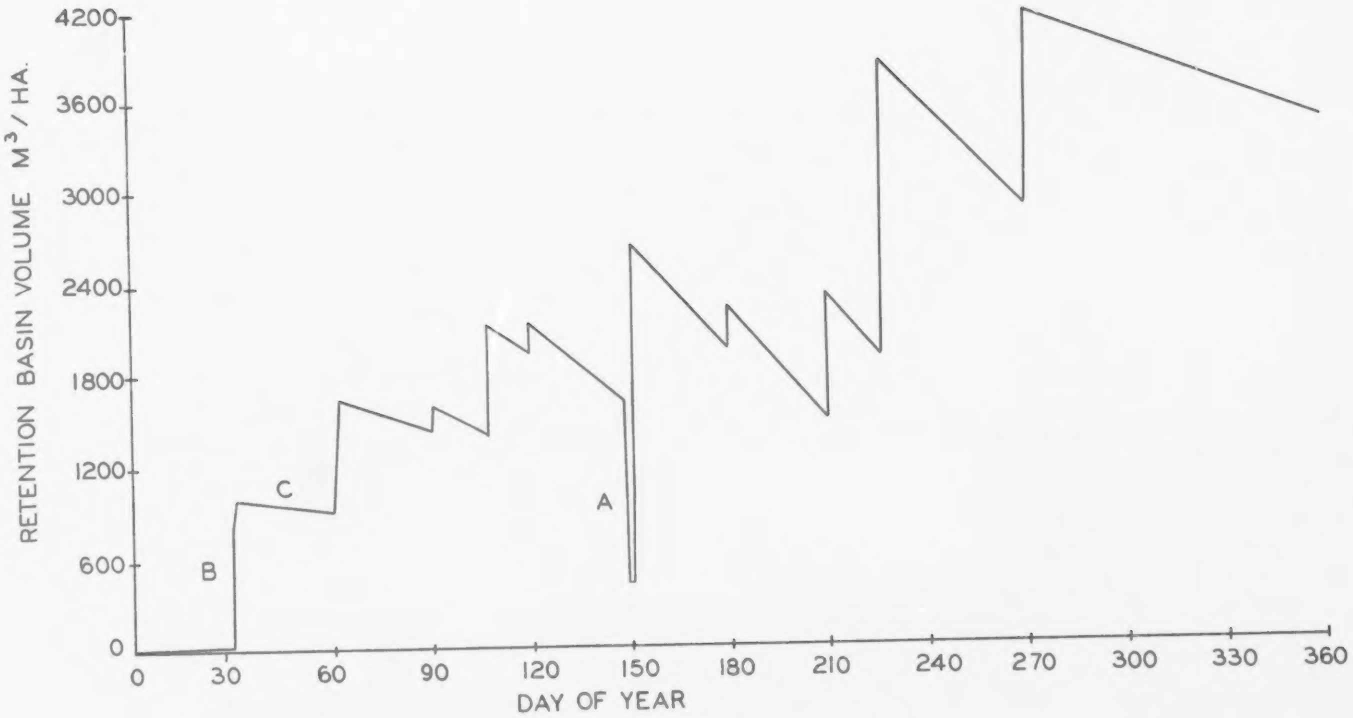

Figure 25. Retention basin volume during a hypothetical year.

Notes:
A. Basin pumped, 0.75 of volume removed
B. Runoff of snowmelt
C. Pond volume decrease due to evaporation

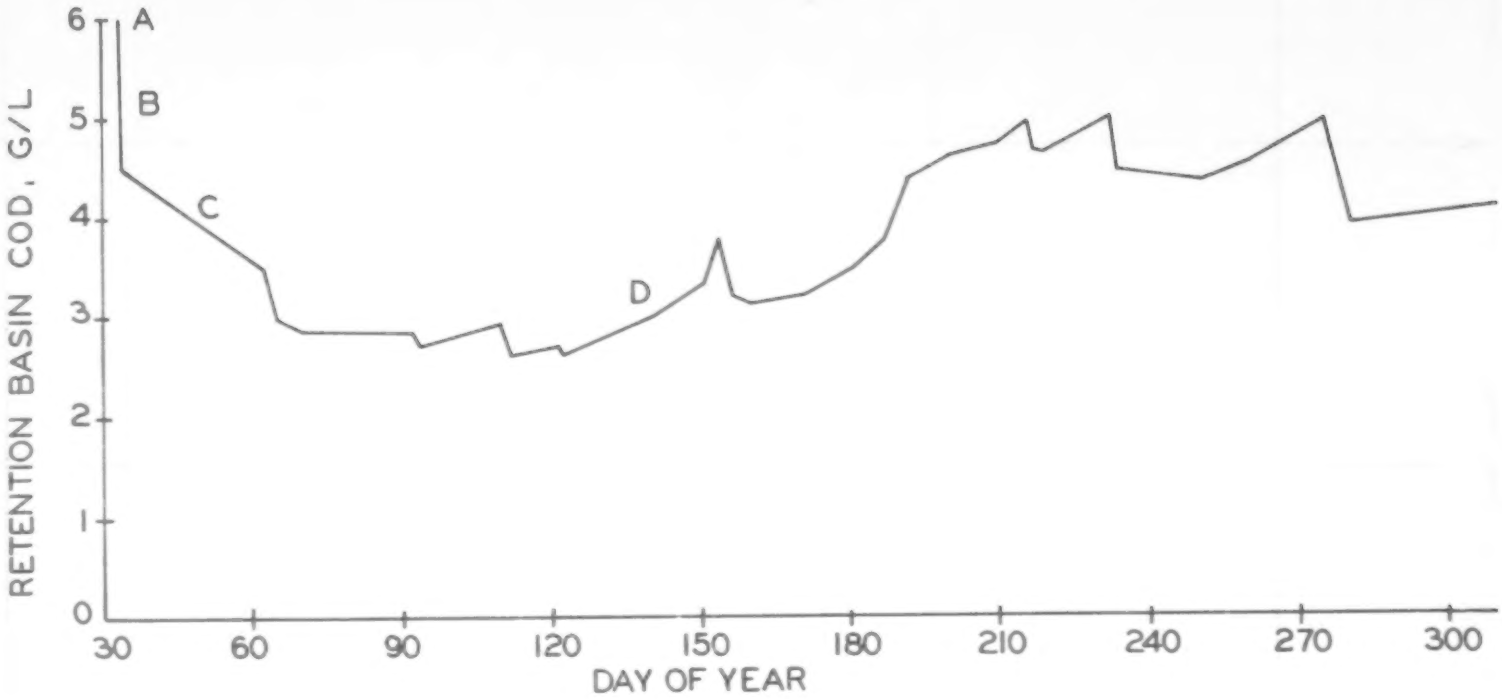

Figure 26. Retention basin COD concentration during a hypothetical year.

Notes:
- A. Incoming snowmelt
- B. Dilution by less concentrated runoff
- C. Stabilization of pond liquid, low temperature
- D. Increase due to sludge liquefaction

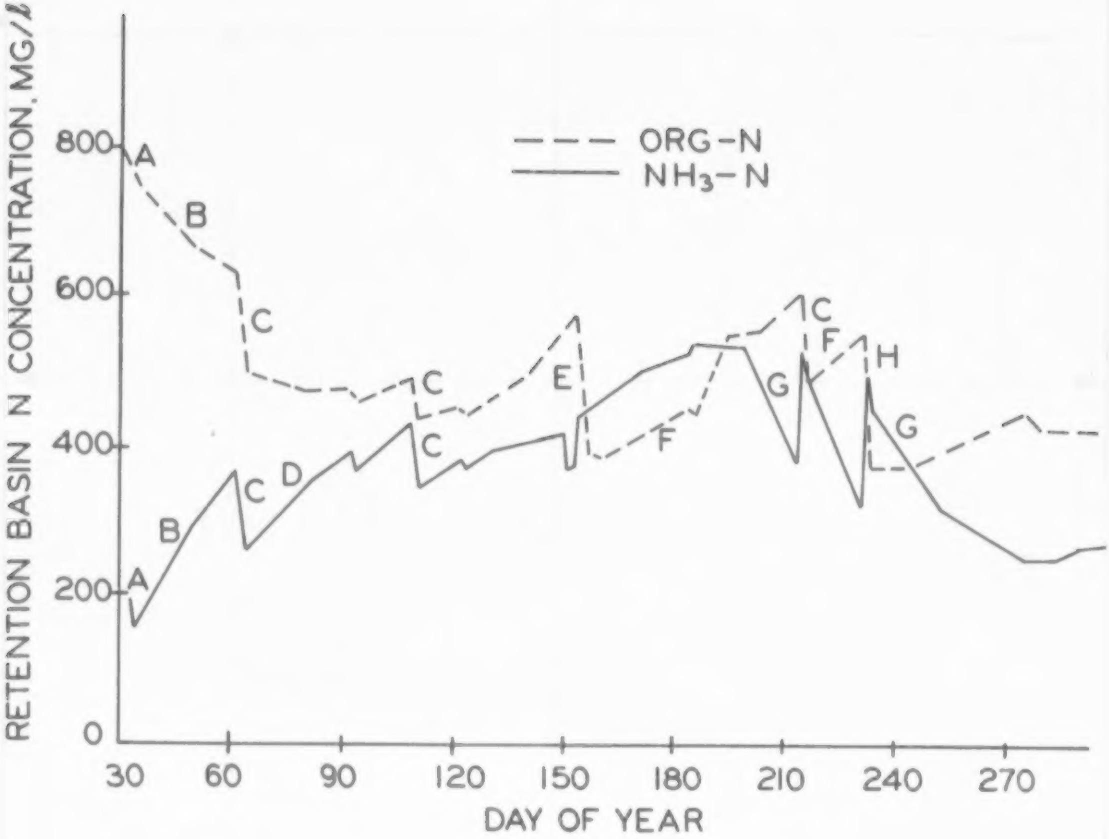

Figure 27. Retention basin NH$_3$-N and Org-N concentrations during a hypothetical year.

Notes:
- A. Snowmelt runoff
- B. Ammonification of Org-N
- C. Dilution by rainfall runoff
- D. Ammonia contribution of sludge
- E. Three successive days of runoff
- F. Increase due to sludge liquefaction
- G. Ammonia volatilization
- H. Heavy August rainfall

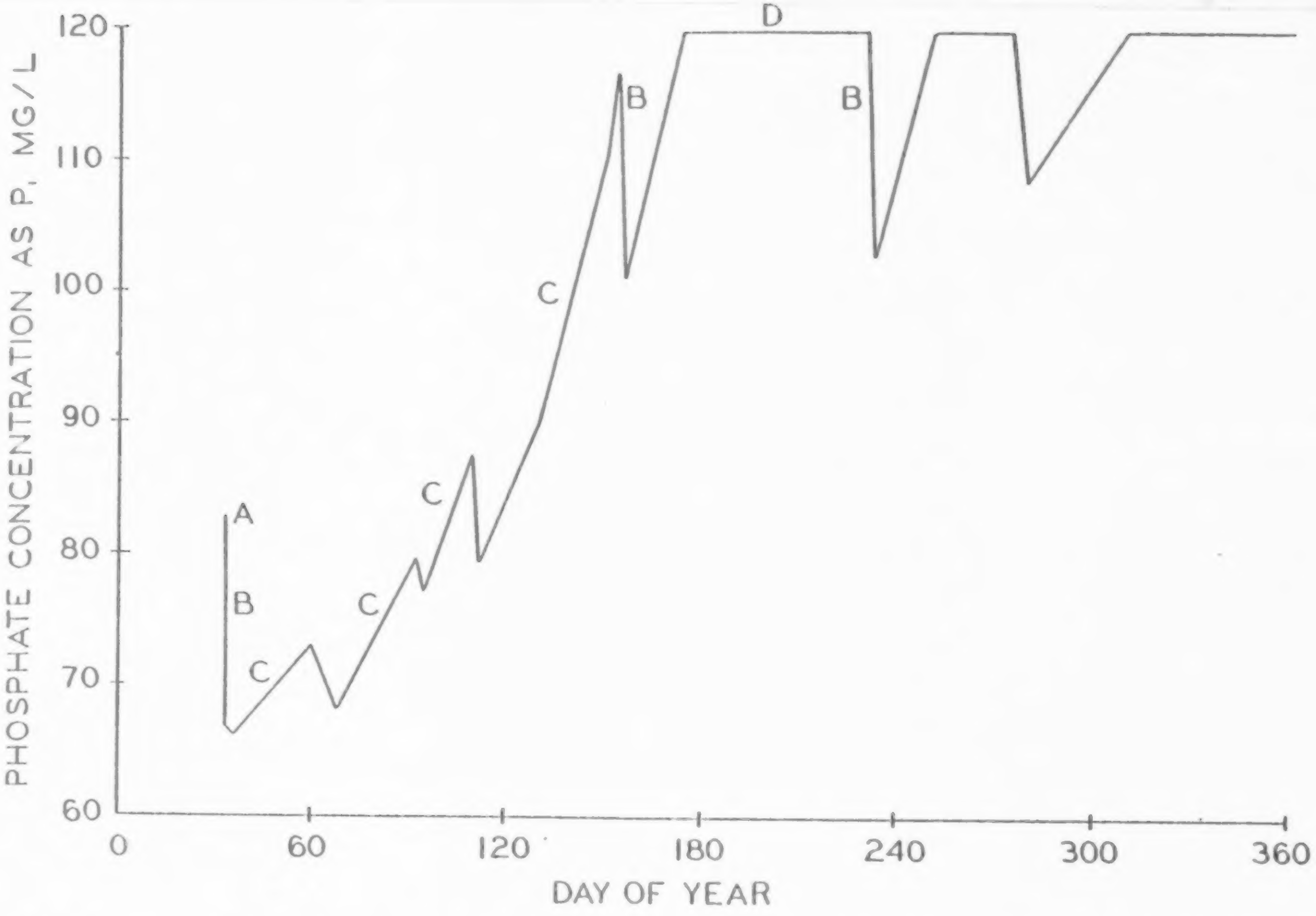

Figure 28. Retention basin Total-P concentration during a hypothetical year.

Notes:
A. Snowmelt runoff
B. Dilution by runoff
C. Release of P from sludge layer
D. Limiting P concentration

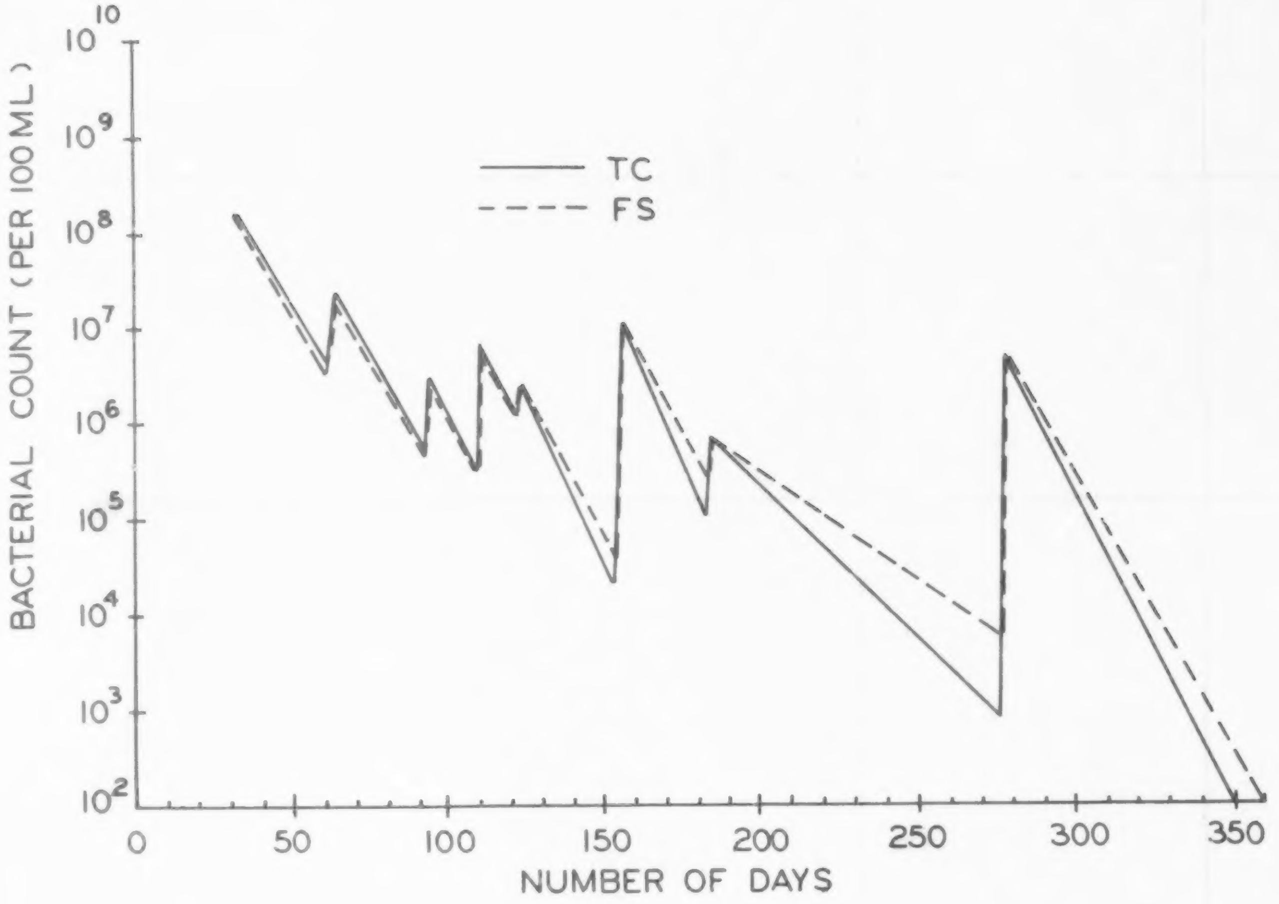

Figure 29. Retention basic TC and FS organism concentration during a hypothetical year. FC were half the TC.

SECTION 10

MODELING OF AMMONIA LOSSES IN SPRINKLER APPLICATION OF ANIMAL WASTES

Information exists on the amount of N in the raw wastes, as well as rough approximations of percentage loss expected for various handling methods. Only relatively recently has any real effort been made to model such losses in a form adaptable to a variety of real situations. One area in which predictions have been limited to broad estimates has been losses during sprinkling.

Research has been done on NH_3-N losses during spray application of liquid NH_3-N fertilizers, but most of this has been simple data collection and study of factors affecting losses. Since any predictions made were strictly empirical and based on a minimal consideration of variables, the applications of these studies are extremely limited.

The objectives of this study were to develop a model capable of predicting NH_3-N losses from sprinkler applied animal wastes. The model was designed to consider a large number of variables and to provide a rational approach to increase the reliability of the predictions under a variety of conditions. Data were collected for a system with all variables noted, and the results compared to the predictions of the model. Lastly, the model's predictions were compared to the data of past studies to note similarities and differences.

BACKGROUND

Various people have examined losses of NH_3-N during sprinkling of liquid fertilizers. Henderson, et al. (1955) sprayed aqua ammonia (NH_4OH), ammonium phosphate [$(NH_4)_2H\ PO_4$], and ammonium nitrate (NH_4NO_3) on a gridded field. Losses were examined and curves developed predicting percent NH_3-N lost with increasing concentrations of NH_3-N and the various ammonium salts. While the curves of percent loss versus concentration varied according to the NH_3-N form being considered the various curves can be combined into a single curve for the graph of percent NH_3-N loss versus pH (Figure 30). Henderson, et al. (1955) also suggested that percent NH_3-N loss should be related in some way to temperature variations.

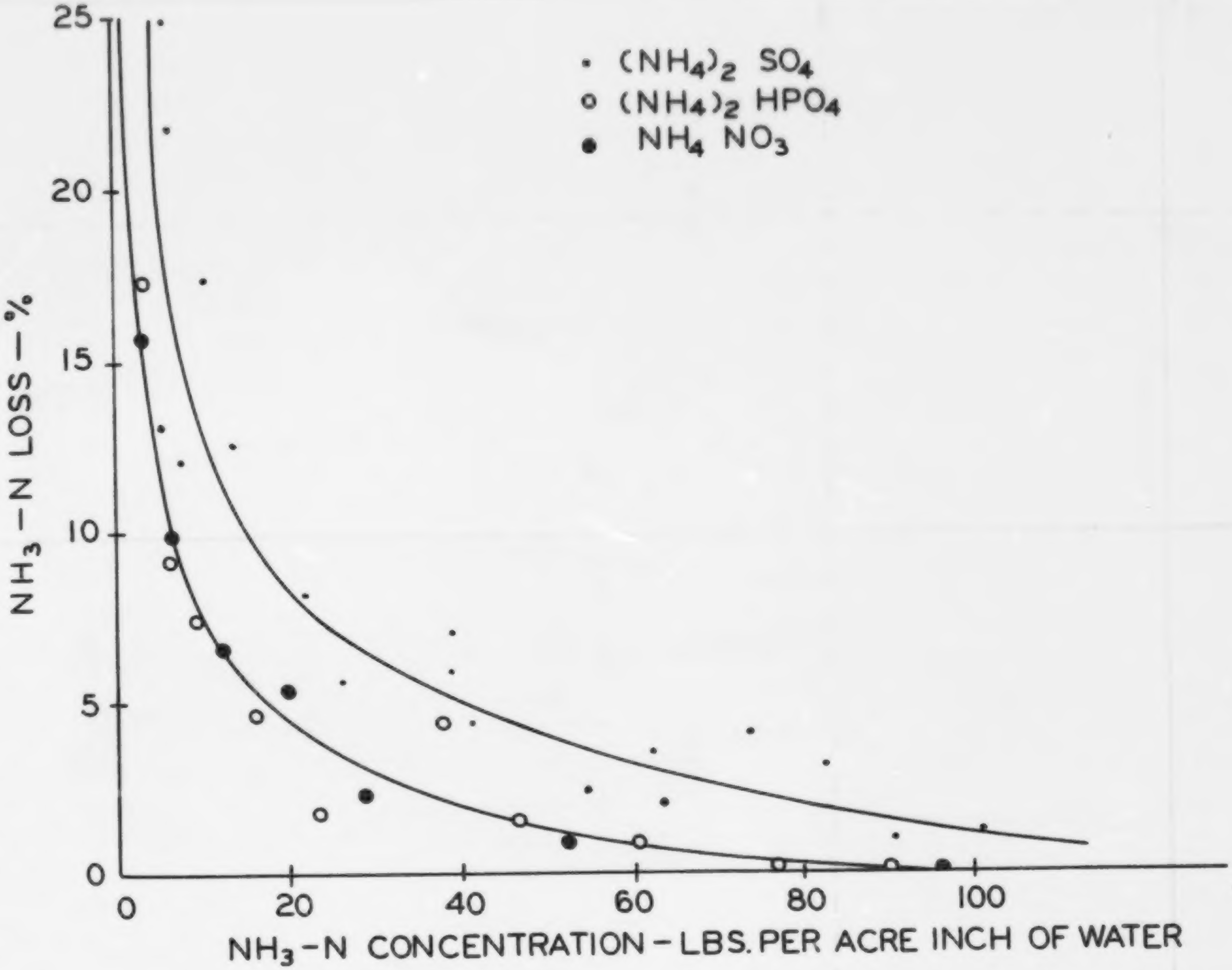

Figure 30. Losses of NH_3-N from fertilizer salts in relation to NH_3-N concentration in the irrigation water (Henderson, et al., 1955).

Miyamoto (1955) examined optimum pH and concentrations for sprayed NH_3-N fertilizers and the feasibility of reaching the desired pH by addition of acid. His study of NH_3-N losses with increasing pH closely paralleled that of Henderson, et al. (1955). A pH of 7.5 or below gave insignificant losses.

Jackson, et al. (1959) examined the losses of NH_3-N during spraying of NH_3-N solutions with variables of distance sprayed, NH_3-N concentration, initial temperature of the solution, and pH. Losses with concentration and water temperature were matched with curves which showed an increase in NH_3-N loss with an increase in either. In addition, data showed increased losses with increased pH and distance sprayed.

All of these investigators noted that there will be some evaporation of NH_3-N after the droplet has struck. Although some considered this loss to be large, none attempted to quantify it in any way. Some assumed such losses to be negligible.

Roessler, et al. (1971) examined the rate of NH_3-N loss in the NH_3-N stripping process, using an "ammonia transfer unit height," the distance over which a certain amount of NH_3-N is lost, in their case, "the height in feet which the spray must fall to lose a pound mole of nitrogen per cubic foot of spray." This height varied according to system used, and was calculated from collected data for wood-slat-packed stripping towers.

This model began with a mass balance for NH_3-N in the tower, so that air flow rate multiplied by change in concentration of NH_3-N in air equals liquid flow rate times change in concentration of NH_3-N in water. This was added to a similar analysis of heat transfer and thus cooling in the tower to calculate the change in Henry's Law Constant, according to the empirical relation

$$K_H = 0.1117\, e^{0.02612T} \tag{65}$$

where:

K_H = Henry's Law Constant (dimensionless)

T = temperature ($^{\circ}F$)

Also, empirical relationships were developed for predicting pressure changes and systems' costs.

FORCES ACTING ON A DROPLET

For the purpose of developing a predictive model for the loss of NH_3-N in sprinkling, the most logical approach seemed to be modeling the losses from a single droplet shot from a sprinkler, and expanding losses from the "average droplet" for the system to calculate losses for the entire sprinkler and sprinkler system.

Welty, Wicks, and Wilson (1976) described the forces acting on a single droplet. The droplet, once launched tends to decrease in speed due to drag force, and to increase in speed (or decrease, depending on direction of launch) due to gravity. Since the droplet is evaporating and velocity is changing, the drag force is continually being altered at a varying rate. The changing drag force, in turn, alters the rate of change of velocity. Likewise, the change in velocity and the change in surface area will affect the rate of evaporation. One of the major obstacles to the project was describing all of these variables in order to predict NH_3-N losses. The modes of NH_3-N loss would be similar in nature to those of water loss, but would have to include a concentration factor, since volatilization of NH_3-N would tend to decrease concentration and, thereby, rate of NH_3-N loss, while decreasing droplet size would tend to increase both.

Frost and Schwalen (1956) studied water losses from sprinkler systems. Variables included humidity, air temperature, nozzle diameter and wind velocity. Some of their conclusions were as follows:

1) Evaporation losses on humid, windless, cool days averaged about 3 percent, while losses on humid, windless, hot days averaged about 10 percent.

2) Raising the nozzle pressure from 210 to 350 kPa (30 to 50 psi) increased losses, and the difference increased as temperature rose and humidity dropped.

3) At high wind velocities losses increased due to droplets being carried outside the testing area. Since this "wind drift" did not noticeably moisten the ground, it was counted as a total loss. Doubling the wind velocity doubled the losses.

4) Losses increase with temperature, wind velocity, operating pressure and degree of breaking of spray and decrease with increase in humidity and nozzle diameter. They are most directly related to vapor pressure deficit which is a function of temperature and relative humidity.

Frost and Schwalen's concept of "wind drift" creates a dilemma in modeling. Although the spray does not fall on the test plot, it does fall somewhere, and with a field significantly larger than the test plot, most will end up on the irrigated field. Likewise, whatever NH_3-N is dissolved in it will reach the field, if not diffused into the air first. Even if the assumption that water contributions to the field from wind drift is negligible holds true, the same is not necessarily acceptable for NH_3-N.

Seginer (1971) modelled water losses during sprinkling based on a description of the forces involved as conductances and resistances yielding a net mass transfer. The model begins by assuming that a standard situation in which losses are non-existent can be approximated by operating during a calm, cool night. Losses in other situations are compared to this case.

Possible water losses were then broken down into three subcategories: 1) spray evaporation from the droplets, 2) surface evaporation after droplet impact, and 3) drift losses or "wind drift."

In each evaporation case, loss rates were described via the conductance to an intermediary point (the spray level) and then a total conductance into the atmosphere well above the field (Figure 31). Conductance was defined such that

$$S = \rho C_s (q_s - q) \tag{66}$$

and

$$A = \rho C_a (q_a - q) \tag{67}$$

and

$$S + A = \rho C_t (q - q_r) \tag{68}$$

where:

S = spray evaporation (g/cm^2S)

A = surface evaporation (g/cm^2S)

ρ = density of the fluid (g/cm^3)

C_s = conductance for vapor transfer between spray and air (cm/S)

C_a = conductance for vapor transfer between wet surface and air (cm/S)

C_t = conductance for vapor transfer from spray level upward (cm/S)

q_s = specific humidity at spray (dimensionless)

q_a = specific humidity at spray droplet surface (dimensionless)

q_s = specific humidity at wet surface (dimensionless)

q = specific humidity at spray level (dimensionless)

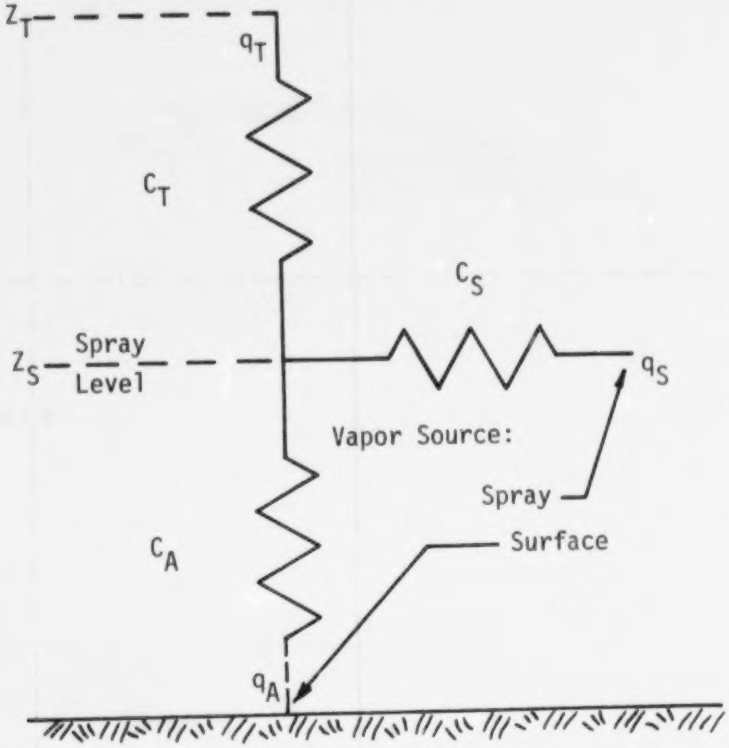
Z_T
q_T
C_T
C_S
Z_S
Spray
Level
q_S
Vapor Source:
Spray
Surface
C_A
q_A

Figure 31. A resistance model of evaporation during sprinkling (Seginer, 1971).

q_t = specific humidity at upper level (Z_T) (dimensionless)

Seginer then analyzed the conductances, finding

$$C_a = \frac{k\ u^*}{\ln \frac{Z_s}{Z_o}} \tag{69}$$

$$C_t = \frac{k\ u^*}{\ln \frac{Z_t}{Z_s}} \tag{70}$$

where:

k = von Karmann constant (dimensionless)

u^* = friction velocity (cm/S)

Z_s = level representative of spray (cm)

Z_T = level where variation in application does not affect specific humidity (cm)

Z_o = ground level (cm)

For the spray,

$$C_s = \frac{R\ \overline{h}\ \overline{t}}{P\ C_p\ \overline{d}} \tag{71}$$

where:

R = application rate (cm/S)

$\overline{h}$ = average value of heat transfer coefficient ($cal/S \cdot cm^3 \cdot {}^oC$)

P = density of fluid (g/cm^3)

C_p = heat capacity (at constant pressure) of the fluid (cal/g^oC)

$\overline{d}$ = average diameter of droplet (cm)

$\overline{t}$ = average length of time the droplet travels (sec)

For the drift, it was assumed that in a large, homogeneous field, there would essentially be no losses, since fine spray would eventually descend within the field. It was also noted that although possible drift losses cannot be described by energy balances, these losses will be directly proportional to rate of application, so that graphically, spray, surface, and wind drift losses can be shown as in Figure 31.

Experimentation centered around variation of water losses with solar intensity, with the assumption that temperature, humidity, and wind speed variation correlate closely with solar intensity changes. For this case such an assumption was justified, since the research was done in Israel, where there is very little variation in summer weather from day to day.

Finally, Goering, et al. (1975) modelled a single droplet launched and the forces acting on it, and developed a computer program to simulate the resulting trajectory and evaporation losses. As this model and program were of extreme importance to the investigation, what follows will develop the model, reviewing pertinent background literature.

In 1924 Lewis and Whitman (1924) proposed that mass transfer between gas and liquid phases required passage through two films at the interface. Rate of mass transfer is dependent upon the resistance of those two films, which Lewis and Whitman theorized could be added for total resistance. More recently, investigators have proven that a resistance exists at the interface itself if dust or other foreign particles are carried by the liquid. However, the two-resistance theory is still most commonly used, particularly for interpreting, and making predictions from industrial data (Figure 32).

Since, according to Fick's first law, the flux of a substance through a plane perpendicular to the direction of diffusion is directly proportional to the concentration gradient, the molar flux can be expressed by

$$N_{A,g} = k_g(P_{A,g} - P_{A,i}) \tag{72}$$

and $$N_{A,g} = k_1(C_{A,g} - C_{A,i}) \tag{73}$$

where:

$N_{A,g}$ = rate of diffusion of component A on the gaseous side of the interface (mole/s·m^2)

$N_{A,g}$ = rate of diffusion of component A on the liquid side of the interface (mole/s·m^2)

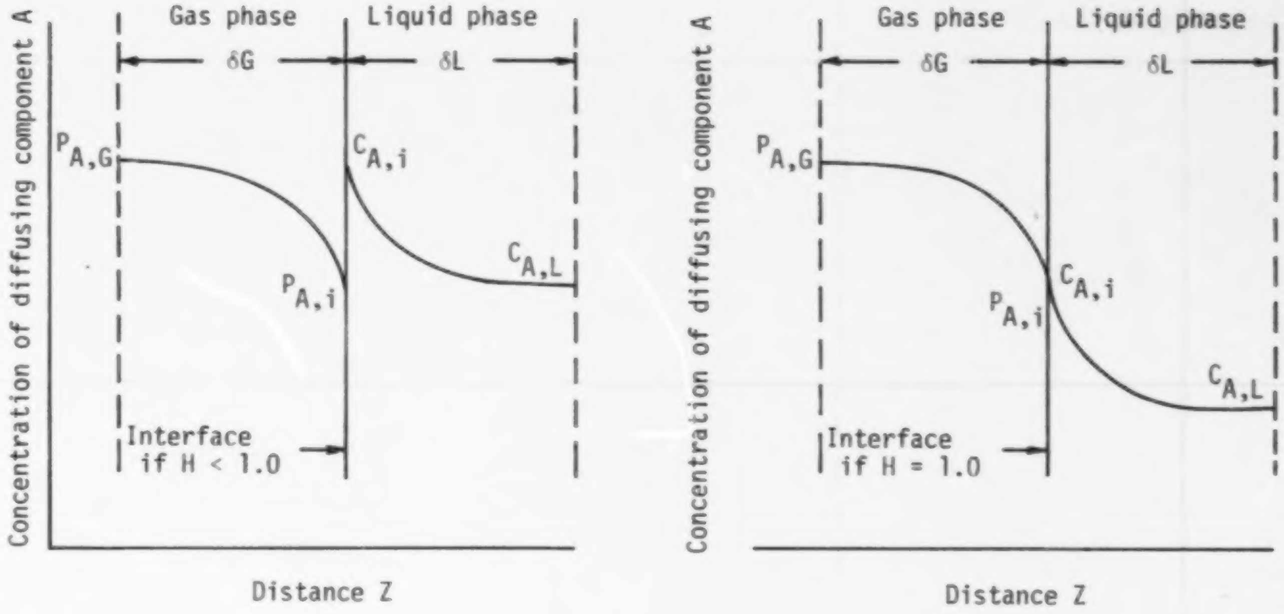
Gas phase
Liquid phase
δG
δL
$P_{A,G}$
$C_{A,i}$
$P_{A,i}$
$C_{A,L}$
Interface
if H < 1.0
Concentration of diffusing component A
Distance Z
Gas phase
Liquid phase
δG
δL
$P_{A,G}$
$C_{A,i}$
$P_{A,i}$
$C_{A,L}$
Interface
if H = 1.0
Concentration of diffusing component A
Distance Z

Figure 32. Concentration gradients between two contacting phases (Welty, et al., 1976).

k_g = convective mass transfer coefficient for diffusion of vapor through a second, non-diffusing component

k_l = convective mass transfer coefficient for diffusion of liquid through a second, non-diffusing component

$P_{A,g}$ = partial pressure of component A in the bulk gas phase (Pa)

$P_{A,i}$ = partial pressure of component A at the interface (Pa)

$C_{A,i}$ = concentration of component A at the interface (moles/m^3)

$C_{A,i}$ = concentration of component A in the bulk liquid phase (moles/m^3)

At the interface, P_A,i and C_A,i are related according to Henry's Law, just as at equilibrium, that is

$$P_A = H\ C_A \tag{74}$$

where:

H = Henry's Law constant $(\mathrm{Pa}/\frac{\mathrm{mol}}{\mathrm{m}^3})$

For a falling droplet of pure water, there is no concentration gradient within the liquid phase, therefore diffusion from the droplet can be described by Equation 72 alone.

In their study of evaporation of droplets in connection with spray drying, Ranz and Marshall (1958a) used Equation 72, but multiplied by the surface area of the droplet (assumed spherical) and the molecular weight of water, so that

$$\frac{dm}{dt} = k_g\ A_s\ \Delta P\ M_v \tag{75}$$

where:

$\frac{dm}{dt}$ = rate of mass transfer (g/s)

A_s = surface area of the droplet

ΔP = vapor pressure difference (between droplet surface and bulk air)

The equation is basically the same as that employed by Koelliker and Miner (1973). However, the approach to finding the value of K_g differed.

Through Nusselt's work in energy transfer, use of a dimensionless number (called a Nusselt number) characteristic of fluids and their convective and conductive thermal resistances developed. In the analagous case in mass transfer, the mass transfer Nusselt number or Sherwood number, as it is sometimes known, is evaluated as

$$Nu_{AB} = \frac{k_c L}{D_{AB}} \tag{76}$$

where:

Nu_{AB} = the mass transfer Nusselt number for a system of components A and B (dimensionless)

k_c = convective mass transfer coefficient $\left(\frac{\text{mols}}{m^2 \cdot s \cdot \text{mols}/m^3}\right)$

L = length (in)

D_{AB} = mass diffusivity or diffusion coefficient for component A diffusing through component B (m^2/s)

Later investigators (Welty, et al., 1976) found the Nusselt number for a sphere to vary in the form

$$Nu_{AB} = Nu_{ABo} + Cre^{\frac{1}{2}}\, Sc^{1/3} \tag{77}$$

where:

Nu_{ABo} = the Nusselt number at very low Reynold's number; $Nu_{ABo} = 2.0$ (dimensionless)

C = correlating constant (dimensionless)

Re = Reynold's number; $Re = \frac{LV}{v}$ (dimensionless)

where: V = velocity (m/s)

v = kinematic viscosity (m^2/s)

Sc = Schmidt number; $S_c = \frac{m}{\rho\, D_{AB}}$ (dimensionless) where: m = viscosity (Pa·s)

ρ = density (kg/m^3)

Fröessling* found that for this system, C equals 0.552. Later studies by Ranz and Marshall (1952a) adjusted the value to 0.5, so that the equation becomes

$$\frac{k_c\ D_p}{D_{AB}} = 2.0 + 0.6\ Re^{\frac{1}{2}}\ Sc^{1/3} \tag{78}$$

Marshall (1954) used this equation for the evaporating droplet, and multiplied by factor of

$$\frac{\rho_a}{M_m\ \rho_f}$$

where:

pa = density of air (g/cm^3)

Mm = mean molecular weight of gas mixture in transfer path (g/mol)

P_f = partial pressure of air (dynes/cm^2)

This factor changes k_c to k_g and the units from $\dfrac{\text{moles}}{m^2 \cdot s \cdot \frac{\text{mols}}{m^3}}$ to $(\dfrac{\text{moles}}{m^2 \cdot s \cdot Pa})$, so that the equation becomes tailored to a vapor system. The equation for k_g is now

$$k_g = \frac{D_{AB}\ \rho_A}{Mm\ D_p\ P_f}\ (2.0 + 0.6\ Re^{\frac{1}{2}} Sc^{1/3}) \tag{79}$$

Since droplets are assumed spherical, the surface area of the droplets is

$$A_s = \pi D_p^2 \tag{80}$$

and $$m = \rho_1 \pi \frac{D_p^3}{6} \tag{81}$$

---

*N. Fröessling, Gerlands Beitr. Geophys., 52, 170 (1938) quoted by Ranz and Marshall (1952a).

where:

ρ_1 = density of the liquid (kg/m³)

The mass transfer rate now becomes

$$\frac{dm}{dt} = \rho_1 \pi \frac{D_p^2}{2} \frac{dD_p}{dt} \tag{82}$$

and

$$\frac{dD_p}{dt} = -2 \frac{M_v}{M_m} \frac{D_v}{D_p} \frac{\rho_A}{\rho_1} \frac{\Delta p}{P_f} (2.0 + 0.6\ Re^{\frac{1}{2}} Sc^{1/3}) \tag{83}$$

for steady state evaporation from a droplet.

Ranz and Marshall (1952a) evaluated D_v for an air-water system as

$$D_v = 5.28 \times 10^{-6}\ T_k^{1.88} \tag{84}$$

where:

D_v = diffusivity (cm²/s)

T_k = temperature (°K)

by best match of graphed data.

Ranz and Marshall (1952b) also made experimental measurements of interior temperature of falling droplets and found them to be approximately uniform throughout and equal to the wet bulb temperature of the surrounding air.

The external forces acting on the droplet were as follows:

Gravity and buoyancy:

$$W = g(\rho_1 - \rho_a) \frac{D_p^3}{6} \tag{85}$$

where:

W = gravitational and buoyant forces (N)

g = acceleration due to gravity (m/s²)

Drag force (King, et al, 1953)

$$D_f = \frac{C_d \; P_A \; A \; V_r^2}{2} \qquad (86)$$

where:

D_f = drag force (N)

C_d = drag coefficient (dimensionless)

$A = \frac{\pi D_p^2}{4}$ = projected area of the particle (m^2)

V_r = velocity of the particle relative to air (m/s)

and

$$C_d = \frac{24}{Re} \; \Big| Re<1$$

$$C_d = f(Re) \; \Big| Re>1$$

where $f(R_e)$ is Eisner's classic empirical relationship (Figure 33).

Particle dynamics involved were as follows: Smith (1970) used analysis of momentum changes in an evaporating, falling spray droplet to develop the equation

$$m \frac{dv}{dt} = F - V_e \frac{dm}{dt} \qquad (87)$$

where:

m = mass (kg)

F = an external force acting on the droplet (N)

V_e = velocity of the ejected (evaporated) mass relative to the droplet, i.e. $V_e = -V_e$

Therefore the movement of the particle due to evaporation is as through subject to an outside force of ($V_e \frac{dm}{dt}$). Obviously, if V_e is opposite in direction to V, this apparent force tends to increase V. The dynamics of the particle, then are as drawn in Figure 34.

The actual force D shown is

$$D = D_f + V_e \frac{dm}{dt} \qquad (88)$$

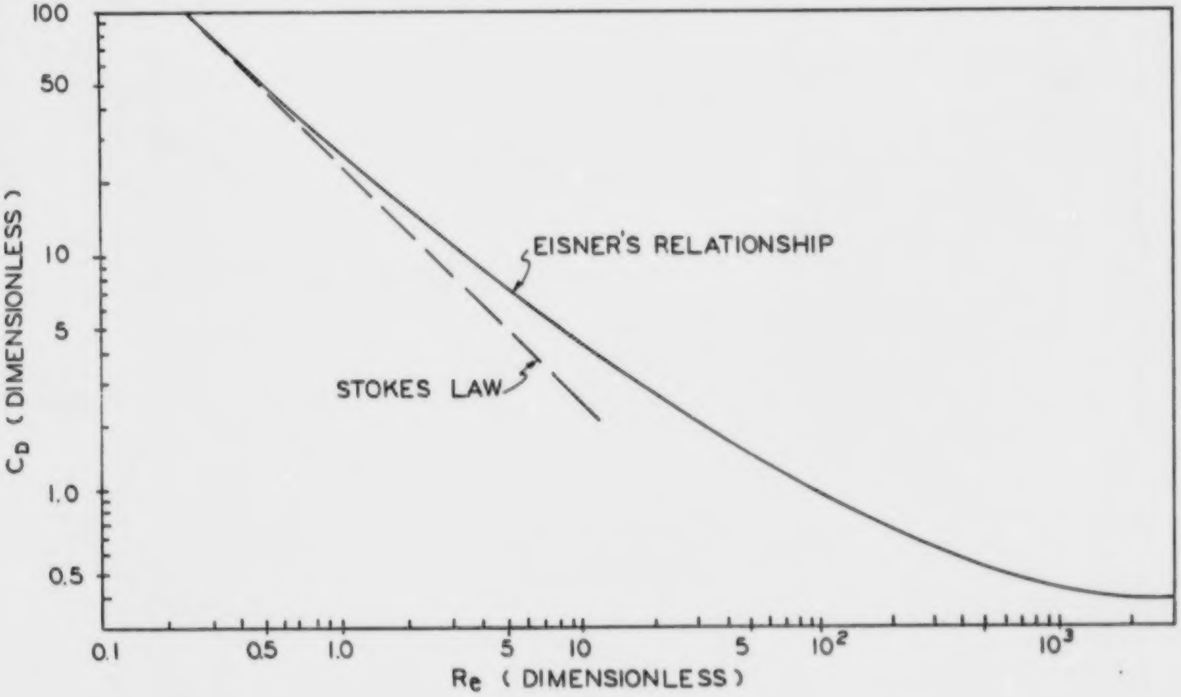

Figure 33. Drag coefficient for a sphere (Sprinkler Irrigation Association, 1975).

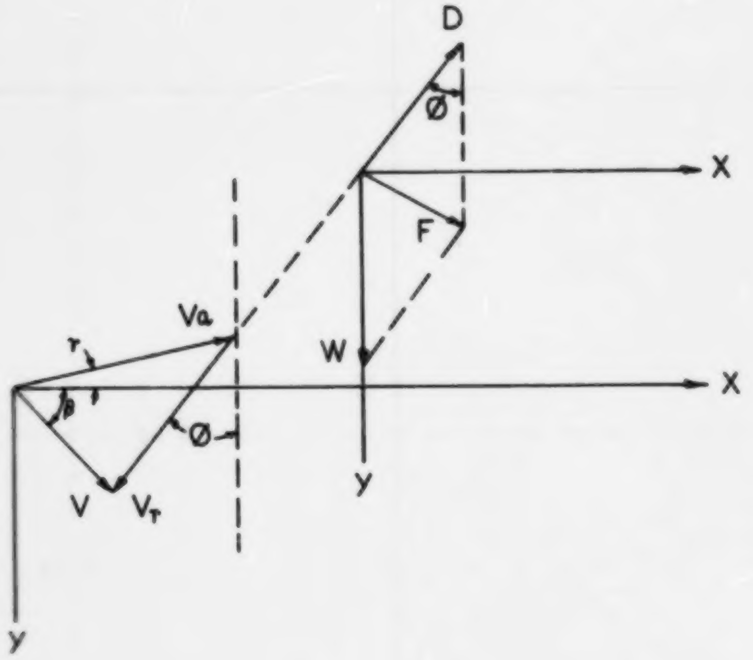

Figure 34. Diagram of particle dynamics (Smith, 1970).

Where: X and y

τ = angle of wind relative to x axis

β = angle of droplet travel relative to x axis

V_a = wind velocity

V = droplet velocity

V_r = droplet velocity relative to air

W = weight and buoyancy

D = drag and evaporative forces

F = combined forces acting on droplet

the sign being negative rather than positive since $(\frac{dm}{dt})$ is negative, i.e. the droplet is losing mass.

X and Y components of force F are

$$F_x = D \sin \phi \tag{89}$$

$$F_y = W - D \cos \phi \tag{90}$$

Droplet acceleration is thus

$$\ddot{x} = \frac{d^2(x)}{dt^2} = \frac{D \sin \phi}{m} \tag{91}$$

$$\ddot{y} = \frac{d^2(y)}{dt^2} = \frac{W - D \cos \phi}{m} \tag{92}$$

Integration with time yields $\dot{x}$ and $\dot{y}$ components of velocity; and velocity

$$V = (\dot{x}^2 + \dot{y}^2)^{0.5} \tag{93}$$

$$\beta = \frac{\pi}{2} - \arcsin(\dot{x}/V) \tag{94}$$

Hence, once the velocity V is known, velocity relative to air is

$$V_r = (V_a \cos \gamma - V \cos \beta)^2 + (V_a \sin \gamma + V \sin \beta)^2 \tag{95}$$

and $$\phi = \arcsin\left(\frac{Va \cos \gamma - V \cos \beta}{Vr}\right) \tag{96}$$

In the model, Eshbach's dynamic viscosity-temperature equation was used.

$$m = (1 \times 10^{-7})\, e^{(1.258 + 0.0012627)} \tag{97}$$

where:

m = dynamic viscosity (lb-sec/ft^2)

T = temperature ($^{\circ}$F)

These equations were used by Goering, et al. (1975) to develop the computer model for a falling, evaporating droplet. The model breaks the fall into very short time periods, estimating the changes during each. The program stops when the drop reaches the ground.

DERIVATION OF EQUATIONS PREDICTING NH_3-N LOSS IN THE MODEL

In order to determine the rate at which NH_3-N is lost from the droplet, it is necessary to return to the original equations by Lewis and Whitman (1974) (Equations 72 and 73) for the two-film, two resistance theory. Since the two resistances are additive, when one is found to be orders of magnitude smaller than the other, it can be assumed to be negligible in comparison. According to Welty, et al. (1976), the relative magnitudes of individual phase resistances depends on the solubility of the gas. For a system involving a soluble gas, such as NH_3-N in water, the gas phase resistance is essentially equal to the overall resistance. In systems involving gases of low solubility, such as carbon dioxide in water, the gas phase resistance may be neglected, and the overall coefficient is essentially equal to the individual liquid phase coefficient. Therefore, in this case, the molar flux rate can be expressed by

$$N_A = k_c (C_{A,s} - C_{A,\infty}) \tag{98}$$

where:

$C_{A,s}$ = concentration of component A at droplet surface

$C_{A,\infty}$ = concentration of component A in bulk air

Assuming the concentration of NH_3-N in the bulk air to be negligible,

$$N_A = k_c C_{A,s} \tag{99}$$

In order to evaluate k_c, Fröessling's equation was used, so that

$$k_c = \frac{D_{ab}}{D_p} (2.0 + 0.6 \, Re^{\frac{1}{2}} \, Sc^{1/3} \tag{100}$$

In Welty, Wicks and Wilson's (1976) tables, they list the value of D_{ab} for NH_3-N/air systems as equal to 0.198 cm/sec at 273°K and 1 atm pressure.

Hirschfelder, et al. (1949) attempted to account for intermolecular forces in order to evaluate the diffusion coefficient for gas pairs of non-reacting molecules, and developed the equation:

$$D_{AB} = \frac{0.001858\ T^{3/2}\ (\frac{1}{M_A} + \frac{1}{M_B})^{\frac{1}{2}}}{P\ \nabla AB^2\ \Omega D} \qquad (101)$$

where:

T = temperature ($^{\circ}$K)

P = pressure (atm)

M_A = molecular weight of species A (g/mol)

M_B = molecular weight of species B (g/mol)

ΩD = the "collision integral"

∇AB = the "collision diameter" for species A and B

Therefore, to correct diffusivity to existing temperatures and pressures,

$$\frac{D_{AB2}}{D_{AB1}} = \frac{T_2^{\ 3/2} P_1}{T_1^{\ 3/2} P_2}\ \frac{\Omega D\ @\ T_1}{\Omega D\ @\ T_2} \qquad (102)$$

Evaluating the quantity $\frac{\Omega D\ @\ T_1}{\Omega D\ @\ T_2}$ at the most extreme temperatures feasible changed the value of D_{AB} by less than 5 percent, and was therefore considered equal to unity, so that

$$D_{AB2} = D_{AB1}\ \frac{P_1}{P_2}\ \frac{T_2}{T_1}^{\ 3/2} \qquad (103)$$

or, using the known values of P_1, T_1 and D_{AB1} as listed in Welty, Wicks and Wilson's (1976) table,

$$D_{AB2} = \frac{4.39 \times 10^{-9} T^{3/2}}{P_2} \text{ in } m^2/s \qquad (104)$$

The dimensionless Schmidt number is

$$Sc = \frac{m}{\rho\ D_{AB}} \qquad (105)$$

but since

$$\rho = \frac{P}{RT} \tag{106}$$

where:

P = pressure (Pa)

R = gas constant $\frac{Pa \cdot m^3}{kg \cdot {}^\circ K}$

T = temperature (K)

combination of equations 104, 105 and 106 and the value of R as 8.314 $\frac{N \cdot M}{mole \cdot {}^\circ K}$

$$Sc = \frac{m}{5.28 \times 10^{-10} T^{\frac{1}{2}}} \tag{107}$$

In order to evaluate the concentration of NH_3-N at the surface of the droplet, $C_{A,s}$, from the concentration in the bulk droplet, $C_{A,l}$, the dimensionless constant K_D was used such that

$$K_D = \frac{C_{A,s}}{C_{A,l}} \tag{108}$$

Note that the value of K_D will be equal to the Henry's Law constant multiplied by $(\frac{1}{RT})$. Since the Henry's Law constant also varies with temperature, no linearity is lost by this combination.

Using tables from Stephen and Stephen (1963), K_D was found to vary with concentration at extremely high concentrations (levels at which ammonia molecules interact), but at reasonably low concentrations, became single valued at constant temperature. The values for varying temperatures were matched within the variation of the experimenters by the formula:

$$K_D = 2.31 \times 10^{-5} T - 6.12 \times 10^{-3} \tag{109}$$

where:

T is in $^\circ K$

By definition,

$$C_{A,s} = K_D C_{A,L} \tag{110}$$

since surface area,

$$A_s = \pi D_p^2 \tag{111}$$

multiplying Equation (41) by the surface area,

$$W_A = \pi D_p^2 \, k_c \, C_{A,s} \tag{112}$$

where:

W_A = mass rate of flow (kg/s)

Note that this equation is identical to Ranz and Marshall's (1952b) (Equation 75) where W_A equals $\frac{dm}{dt}$ with a conversion factor for units.

To find the mass lost within any segment of time,

$$n_{1,i} = W_A(\Delta t_i) \tag{113}$$

where:

$n_{1,i}$ = mass lost in time segment i (kg)

and

$$n_{1,total} = \sum_{o}^{I} n_{1,i} \tag{114}$$

The above equations were added on to Goering, Bode and Gebhart's (1975) program, using the same time increments (Δt) as those in the program. At each t, the variables Re, D_p, $D_{A,L}$, and all values dependent on those variables were recalculated.

Not all of the NH_3-N analyzed as present is actually available for removal during sprinkling. Since NH_3-N is in equilibrium with NH_4^+-N in the form

$$NH_4^+ + \rightleftarrows NH_3 + H^+ \qquad pKa = 9.26$$

only the non-ionized form can actually be volatilized during spraying. Using the Henderson-Hasselblack equation

$$pH = pKa + \log \frac{s}{a} \tag{115}$$

where:

pKa = negative log of dissociation constant

s = concentration of salt form (NH_3)

a = concentration of acid form (NH_4^+)

Using total analyzed NH_3-N as equal to unity, or

$$s + a = 1 \tag{116}$$

$$a = 1 - s \tag{117}$$

Plugging this back into Equation 115 and solving for s yields

$$s = \frac{1}{[\log^{-1}(pKa - pH)] + 1} \tag{118}$$

It was assumed that pH does not change significantly over the period that the droplet is in the air and that the NH_3-N NH_4^+-N equilibrium is reached in a period less than the time increments of the program (more than 10^{-3} seconds).

Therefore, the actual amount of NH_3-N able to be lost was calculated for each iteration as equal to the predicted loss assuming all can be volatilized, times a factor equal to the amount called "s" in Equation 60.

THE MODEL

The model is directly based on Equations 72 through 118. Goering, Bode and Gebhart's model, based on Equations 72 through 97 predicts the droplet's trajectory and evaporation, while Equations 98 through 118 predict NH_3-N losses. There are 13 independent input variables: ambient air temperature, relative humidity, atmospheric pressure, horizontal and vertical components of wind speed, initial spray velocity, horizontal and vertical components of spray direction, nozzle height, nozzle pressure, droplet diameter, NH_3-N concentration and pH. Based on these, all dependent quantities are determined within the program, for example, droplet surface area and rate of mass transfer. Certain quantities are considered constant for a water/NH_3-N/air system, such as density of the droplet, and mean molecular weight of the air.

The model determines initial conditions just prior to ejection, then sends the droplet a short distance (just under a half an inch), based on those conditions. Here the program stops, prints time, x, y, and z components of velocity, x, y, and z components of distance, droplet diameter, Reynold's number, quantity of NH_3-N lost, and percent of NH_3-N left. Next, changing factors are taken into account, those above plus ones dependent on them, such as drag force and NH_3-N concentration. It then calculates the new initial conditions, travels another short distance, and repeats the process until the ground is reached (Figure 35).

The units for the program are varied: Goering, Bode and Gebhart used English units for ease. Although some calculations are then performed in the original units, they change most to the metric, c.g.s. system. All values were reconverted to English units for the output, with the exception of NH_3-N lost, which remains in gram mols, since it was assumed that the user would be more interested in the percentage left.

As the program is presently designed, use is extremely simple. The program requests input variables in specific units:

```
ENTER TEMPERATURE (DEG F)
ENTER RELATIVE HUMIDITY (%)
ENTER ATMOSPHERIC PRESSURE (PSI)
ENTER WIND SPEED COMPONENTS (MPH)
     WXY-MPH
      WZ-MPH
ENTER INITIAL SPRAY VELOCITY (MPH)
ENTER COMPONENTS OF SPRAY DIRECTION
     THETXH
     THETAZ
ENTER NOZZLE HEIGHT (INCHES)
ENTER NOZZLE PRESSURE (PSI)
ENTER MAXIMUM DROPLET DIAMETER (MM)
ENTER INITIAL NH3 CONCENTRATION (MOLS/M3)
ENTER PH
```

The program then reprints the input variable values to assure they are correctly recorded before proceeding with the calculations.

Oddities of the program which should be noted before use are:

1) Angle inputs are in degrees clockwise and are oriented about reference axes in which "Z" is vertical downward, i.e., a droplet ejected at THETXH and THETAZ of zero will be shot directly down toward the ground.

2) Input NH_3-N concentration is in g-mols/m^3.

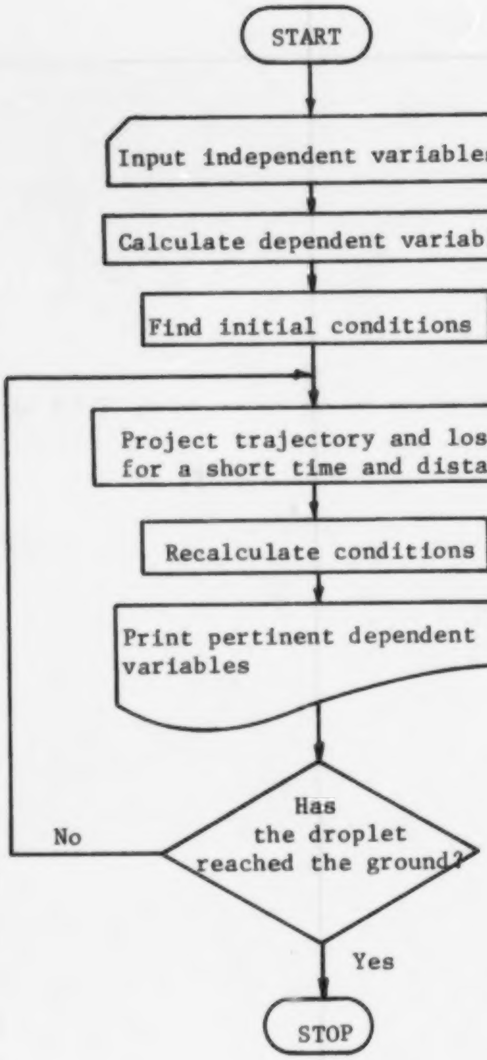
START
Input independent variables
Calculate dependent variables
Find initial conditions
Project trajectory and losses for a short time and distance
Recalculate conditions
Print pertinent dependent variables
Has the droplet reached the ground?
No
Yes
STOP

Figure 35. General flowchart of the programmed model.

3) Read-back of droplet size, to check the input, changes the units from mm to microns and so shows the value increased by a factor of 10^3.

4) Use of wind requires orienting the nozzle correctly to the wind: with THETXH of zero and WXY-MPH greater than zero, wind is coming from directly behind the sprinkler head and ejected droplet. The variable WZ-MPH gives the wind a vertical component of velocity.

5) The printout lists values of time, velocity components, distance components, droplet diameter, Reynold's number, NH_3-N loss, and percent NH_3-N left for each iteration. Cumulative affects are summed so that the last line shows the total time, distance, NH_3-N loss and percent NH_3-N left and the final velocity, droplet diameter, and Reynold's number.

METHODS AND MATERIALS FOR FIELD DATA COLLECTION

In order to collect NH_3-N loss data during sprinkler irrigation of animal wastes, the OSU Swine Research Center waste disposal system was used as the basic source. In that system 800 swine are kept on partially slatted floors over twelve holding pits. Every three to five days the pits are emptied (gravity fed) into an anaerobic lagoon. Although no water is used for the flushing of pits, a considerable volume of water enters the lagoon daily from spillage, a few flush gutters and from the washing of alleys empty into the pits. The lagoon measures approximately 30 m (100 ft) by 40 m (120 ft) by 2.5 m (7.5 ft) deep and its effluent flows into a conical pumping pit 15 m (50 ft) in diameter and 2 m (6 ft) deep. A coarse filter of hardware cloth (Figure 36) prevents solids from clogging the pump. The pump draws effluent from the pit into a sprinkler irrigation system onto surrounding land (Figure 37).

The existing system was modified by the addition of a Manning Proportional Sampler, model S-4040, drawing 400 ml samples from within the pump pit filter every ten minutes. Sample receivers were alternated non-acidified bottles with ones which were preacidified with a few drops of concentrated sulphuric acid to result in a final sample pH less than 3.0, allowing analysis of all nutrients considered pertinent to the study.

In addition, an extra lateral and sprinkler were tapped into the end of the existing irrigation main line. All piping was Moore-Rane "3-inch" aluminum; the sprinkler head was a Rainbird 30 TNT (24) with a 0.35 cm (9/64 in) diameter nozzle. The sprinkler was on a riser 48.3 cm (19 in) above the collector tops and a pressure gauge was tapped into this riser. Pressure remained relatively constant at 5.8 kPa (40 psi) ± 0.3 kPa (2 psi).

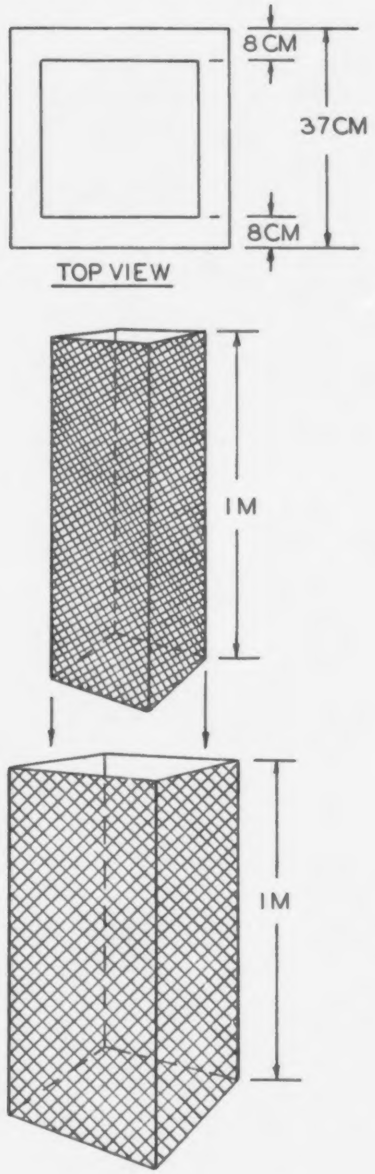
8CM
37CM
8CM
TOP VIEW
1M
1M

Figure 36. Filter design.

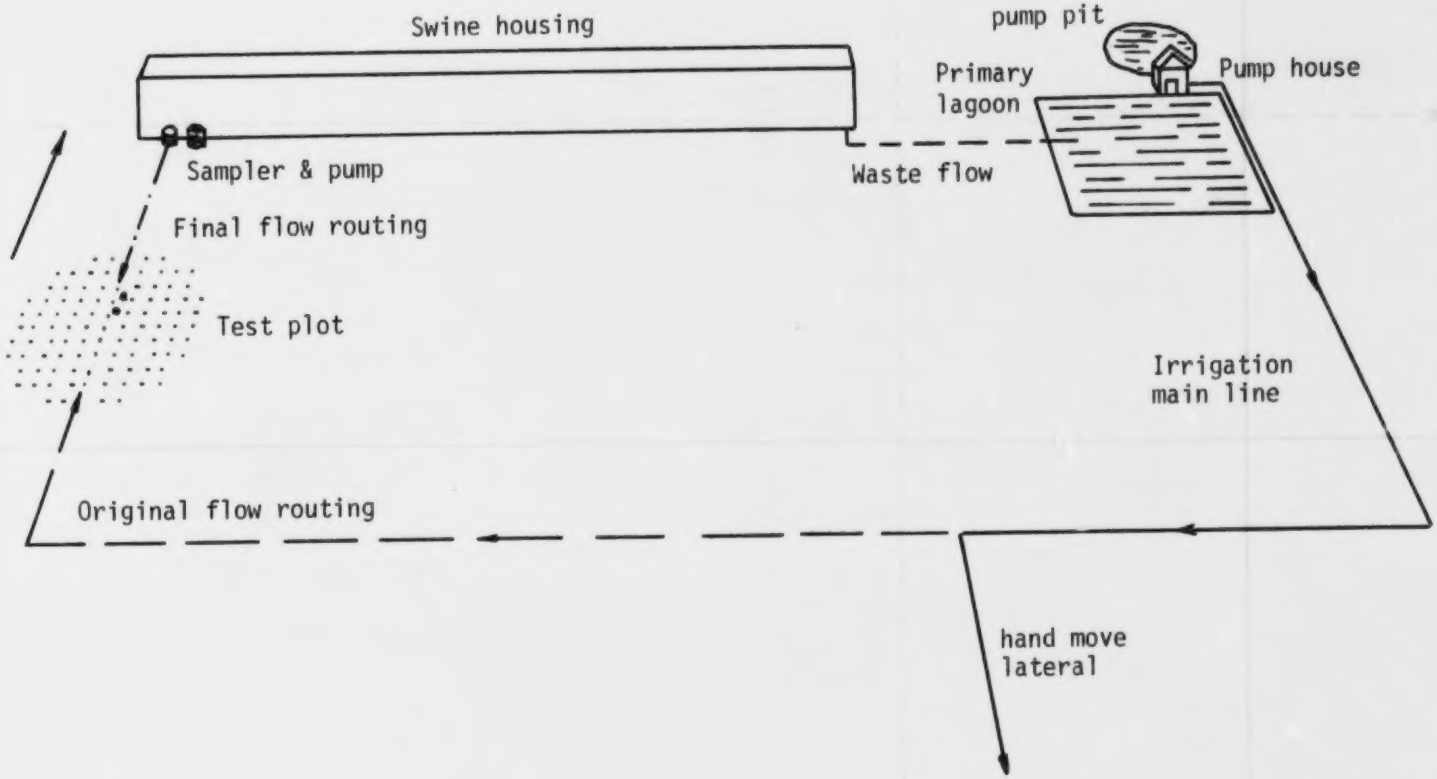
Swine housing
pump pit
Primary
lagoon
Pump house
Sampler & pump
Waste flow
Final flow routing
Test plot
Irrigation
main line
Original flow routing
hand move
lateral

Figure 37. Schematic of swine center with waste disposal system and test plot shown.

The sprinkler was placed in the center of a plot gridded off into 3.0 m (10 ft) squares. The plot location was chosen for flatness and accessibility. Collectors were located at all junctions for a 30.0 m (100 ft) diameter circle (a total of 100), and within a 6.0 m (20 ft) diameter circle, 16 additional collectors were placed to form a grid with 1.5 m (5 ft) separating sprinklers (Figure 38).

Samplers were constructed of PVC "3-inch" piping and bottoms were of flat PVC sheets attached with a solvent cement. Funnels were made of polyurethane, attached to splash cups of PVC with a contact cement. The upper edges of the cups were lathed to form a sharp delineation between those drops entering and those not entering with a minimum of splash (Figure 39). Each, with the exception of one row, was acidified with concentrated sulphuric acid prior to use so that the final sample had a pH less than 3.0.

After a week of sampling (July 15-21), the Swine Center's waste system clogged due to excess solids, and a decision was made to interrupt the system and remove solids from the lagoon. The waste source was shifted to pits beneath the swine, a small contractor's pump providing flow to the sprinkler at the same pressure head. A separate filter was built for the purpose, modelled after the one used in the lagoon. When the pits became low on liquid (a situation which occurred four times in a six-week period) tap water was added and the solution allowed to equilibrate for 24 hours. Concentrations of NH_3-N varied between 50 mg/ℓ and 200 mg/ℓ, the lower value occurring after the addition of water.

When operating, the sprinkler produced two separate spray patterns, one between 3.0 and 15.0 m (10 and 50 ft) from the sprinkler head and one at less than 3.0 m (10 ft). The spray at a distance ("far") was produced by the main spray upwards from the horizontal at 30°. The "near" pattern was produced by the splash of the impactor, and sprayed downward from the horizontal at an average angle of 15°.

The usual run was as follows: The sampler's bottles were acidified (alternate); the field collectors were acidified, except for a single row; the pump was started; the sampler was started; the sprinkler was allowed to drain away from the collectors for a few minutes to assure steady state conditions. During the sampling period (1½ to 2 hours), wind speed, air temperature, and relative humidity were checked twice: wind speed by an anemometer, and relative humidity by sling psychrometer. If wind speed exceeded 7 km/hr (4 mi/hr), or if rain fell, the run was aborted. At the end of the sampling period all systems were shut down, and five samples were carried back; each was formed by combining all samples of a given category in a single vessel, and drawing an "average" sample for that category from the

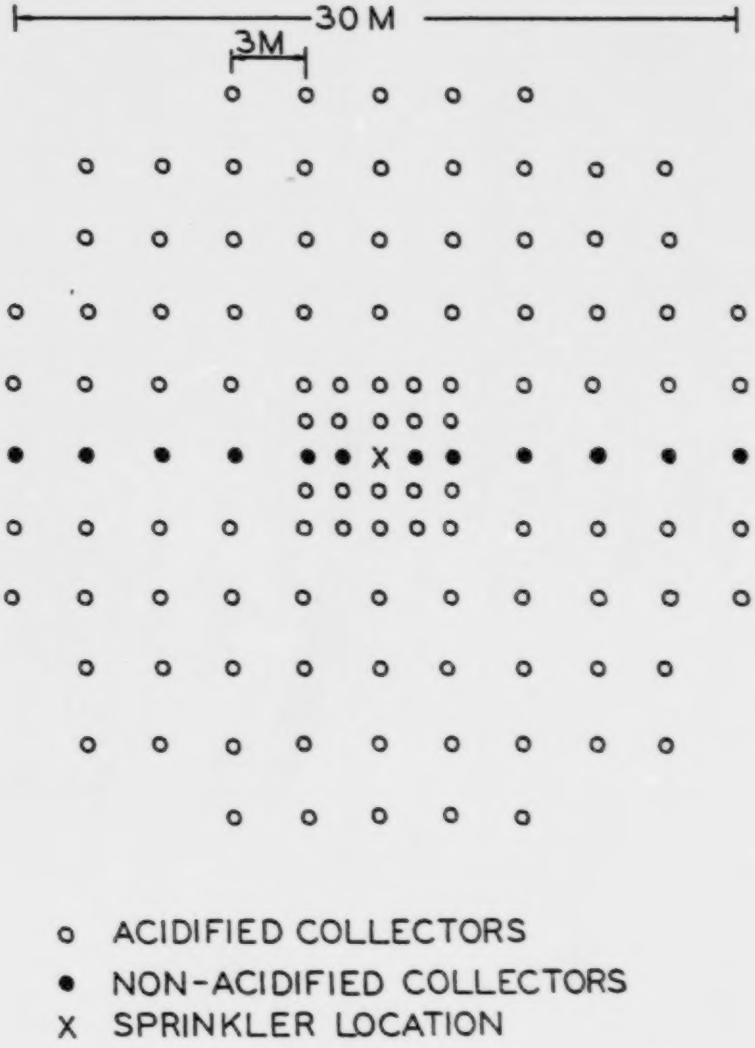
30 M
3M
o ACIDIFIED COLLECTORS
● NON-ACIDIFIED COLLECTORS
X SPRINKLER LOCATION

Figure 38. Grid of collectors.

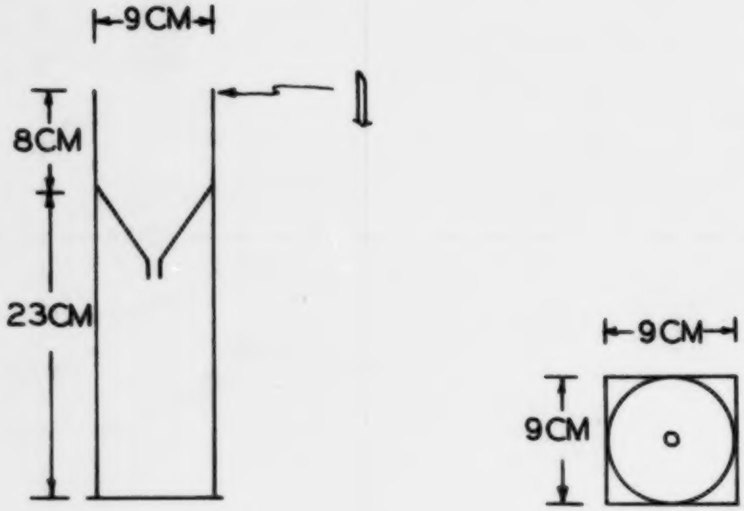
9CM
8CM
23CM
9CM
9CM

Figure 39. Collector design.

vessel. The samples were classified as sampler/acidified, sampler/non-acidified, field/near (acidified), field/far (acidified), and field/non-acidified. These were analyzed within 24 hours. Spot checks of lagoon pH, droplet pH, and lagoon temperature were also made. Droplet pH was measured by catching a small quantity of spray in a beaker and immediately analyzing its pH with field electrode and meter. These results were cross-checked by analyzing pH of non-acidified spray samples in the lab. Lagoon pH was measured both in the field and in the laboratory.

The non-acidified inlet sample and the non-acidified field samples were analyzed for phosphate (PO_4-P), total dissolved solids (TDS), volatile dissolved solids (VDS), TSS, and volatile suspended solids (VSS) concentrations. The acidified samples: "sampler," "near," and "far," were, in addition to NH_3-N, analyzed for TKN and COD concentrations. All analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1976).

NH_3-N analysis was performed according to the suggested method for acidemetric analysis, except that extra duplicates were sometimes performed and titrated with lower concentrations of acid to increase precision. Those samples tested for TKN were also analyzed by acid titration rather than colorimetrically.

PO_4-P was determined colorimetrically by the vanadomolybdic acid method (APHA, 1976). Solids and COD analyses were performed with no variation from the prescribed method.

Droplet size was measured by the method developed by Laws and Parsons (1943) and revised by Meyer (1958). Fresh, bleached, white flour was sifted into pans to a depth of 1.9 cm (3/4 in), then struck off with a straight edge. Within an hour, the pans were exposed to spray. Immediately afterwards, they were dried for 24 hours at 38°C. After drying the flour pellets formed by the droplets were separated from the flour with a 50 mesh sieve. They were then weighed, and the size of the droplet calculated according to Meyer's equation:

$$R = 1.05\ Mp^{0.062} \qquad (119)$$

where:

R = ratio of droplet mass to pellet size

Mp = pellet mass (mg)

The resulting mass was divided by $\frac{\rho_\ell \pi}{4}$ and the square root taken to calculate droplet diameter:

$D_p = 2.76$ mm (0.10 in) for far droplets

$D_p = 1.03$ mm (0.04 in) for near droplets

These agreed fairly closely with Kohl's (1974) analysis of droplets from agricultural sprinklers by the same method.

The velocity of the spray was obtained by using a pitot tube at the nozzle tip. Changing stagnation pressure (psi) to velocity gave an initial velocity for both sprays of 34.2 mph (15.3 m/s).

The pH checks all showed a pH of 7.0 ± 0.1, initially and after spraying. Samples were taken at air temperatures varying from 10° - 32°C. Relative humidity varied from 10 to 90 percent, the former value usually occurring at high temperatures, the latter at low. The exception was one rainy period of about 5 days (August 20-25) when samples were taken and analyzed only if completed before actual precipitation occurred.

Additional analyses were carried out at the end of the testing period (September 7-15) to determine the effects of spraying on TC count and the effect of herbage on NH_3-N loss after droplet impact.

RESULTS AND DISCUSSION

Analysis of data is based on comparison of measured losses to predicted losses. Losses of NH_3-N during sprinkler irrigation of wastes was found by subtracting NH_3-N concentration in field collectors from NH_3-N concentration at inlet sampler, and dividing by inlet sampler's NH_3-N concentration to express losses as percent NH_3-N loss. Analysis of the computer model's prediction of variation of NH_3-N loss with any given factor was performed by plugging in a set of standard conditions and varying only the factor under consideration. The one exception was the variation of temperature and humidity. Collected data showed a definite correlation between temperature and relative humidity, in this case, as shown in Table 9.

Therefore, for studies of individual factors affecting NH_3-N losses temperature and relative humidity were varied simultaneously according to the same pattern. Variations of losses with nozzle pressure change were not investigated to any real extent. As might be expected, using a droplet representative of an average system gives results much closer to those of Henderson, et al. (1955), the down-curved portion still existing, but at a pH too high for practical use. At a pH of 10.5 reference points have been added to show predicted NH_3-N loss for droplets of diameter 0.5 mm (0.02 in), 2 mm (0.08 in), and 3 mm (0.12 in) in the same system (Figures 40 and 41). It is of interest to note

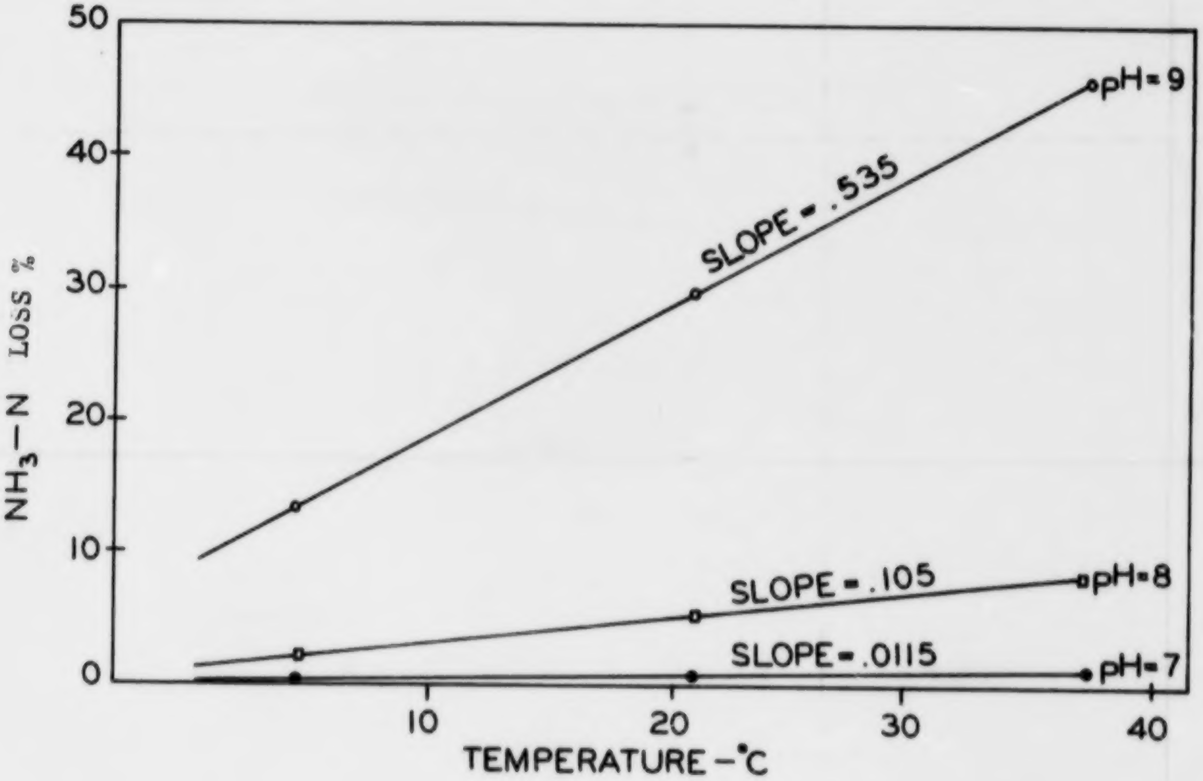

Figure 40. Predicted variation of NH_3-N loss with temperature and pH.

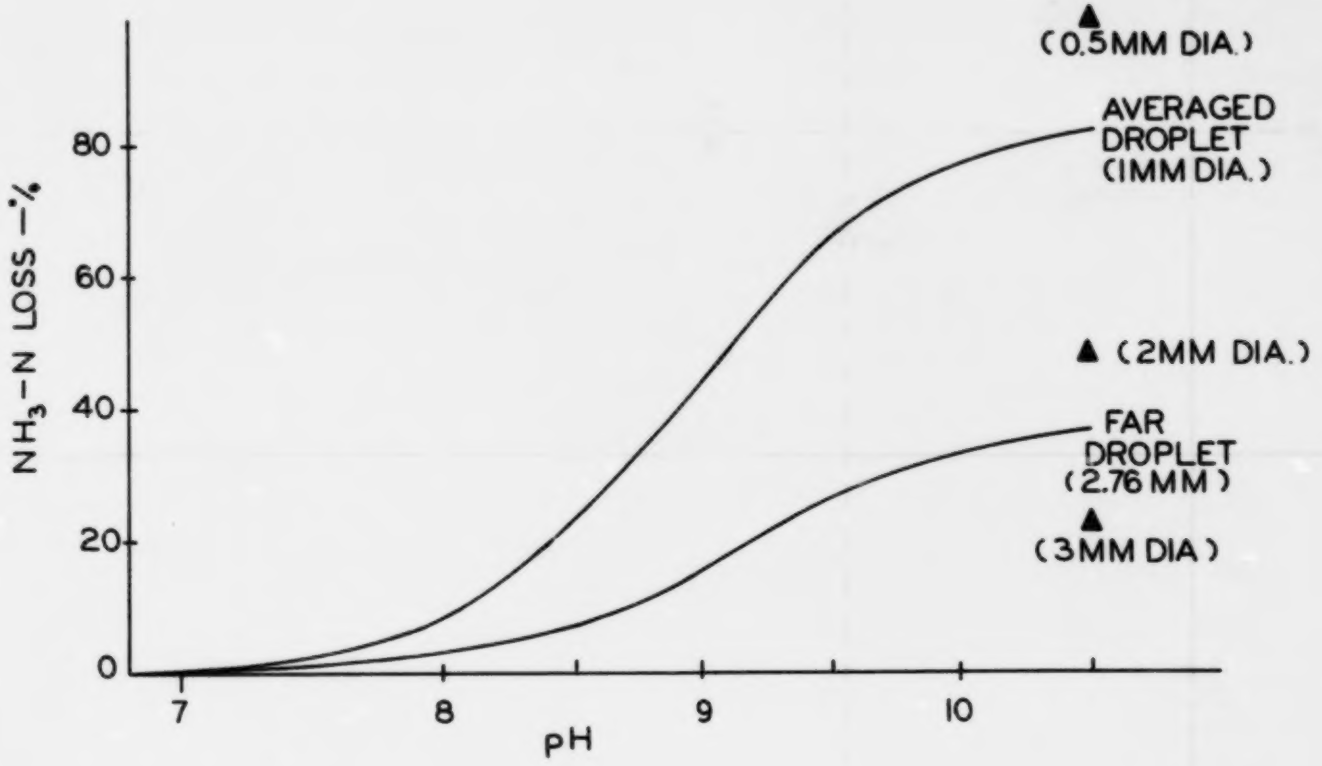

Figure 41. Predicted NH_3-N loss in far spray: variation with pH.

TABLE 9. VARIATION OF RELATIVE HUMIDITY WITH TEMPERATURE DURING STUDY

Temperature (°C)	Relative Humidity (%)
38	0
32	10
27	20
21	40
16	60
10	90
4	100

that a droplet diameter of 2 mm (0.08 in) seems to represent the half-way point at extremely high pH for this system: a droplet of diameter of greater than 2 mm (0.08 in) loses less than 50 percent of its NH_3-N, a droplet of diameter less than 2 mm (0.08 in) loses more than 50 percent of its NH_3-N during flight.

Demonstrated in Figure 42 is the predicted relationship of NH_3-N loss of a droplet to the height of the nozzle at pH of 9. Even at this elevated pH, nozzle height is not the most crucial factor in NH_3-N loss, as an increase of 2 m (6 ft) in nozzle height causes an NH_3-N loss of less than 15 percent added to the original loss of approximately 40 percent. The shape of the curve is slightly convex upward, progressively taller risers producing increases in NH_3-N loss at a decreasing rate.

Analysis of the relationship of NH_3-N loss to velocity and distance travelled was performed by plots of a single dropplet's flight. The droplet was an "average" one at a pH of 10.5. Figure 43 shows the predicted flight of the droplet, while Figure 44 shows the NH_3-N loss plotted against horizontal distance. The rate of loss is almost constant with distance until near the end of the flight; even there the increased rate of loss corresponds to an increased vertical distance travelled, a fact not reflected in the units of the abscissa. Figure 42 in turn shows the change of velocity with respect to distance horizontal from the sprinkler head. It is interesting to note that while the velocity undergoes a change of an order of magnitude, the rate of NH_3-N loss scarcely decreases at all. In general, it seems that although the distance a droplet travels is dependent on the droplet's launch velocity, the NH_3-N loss is more

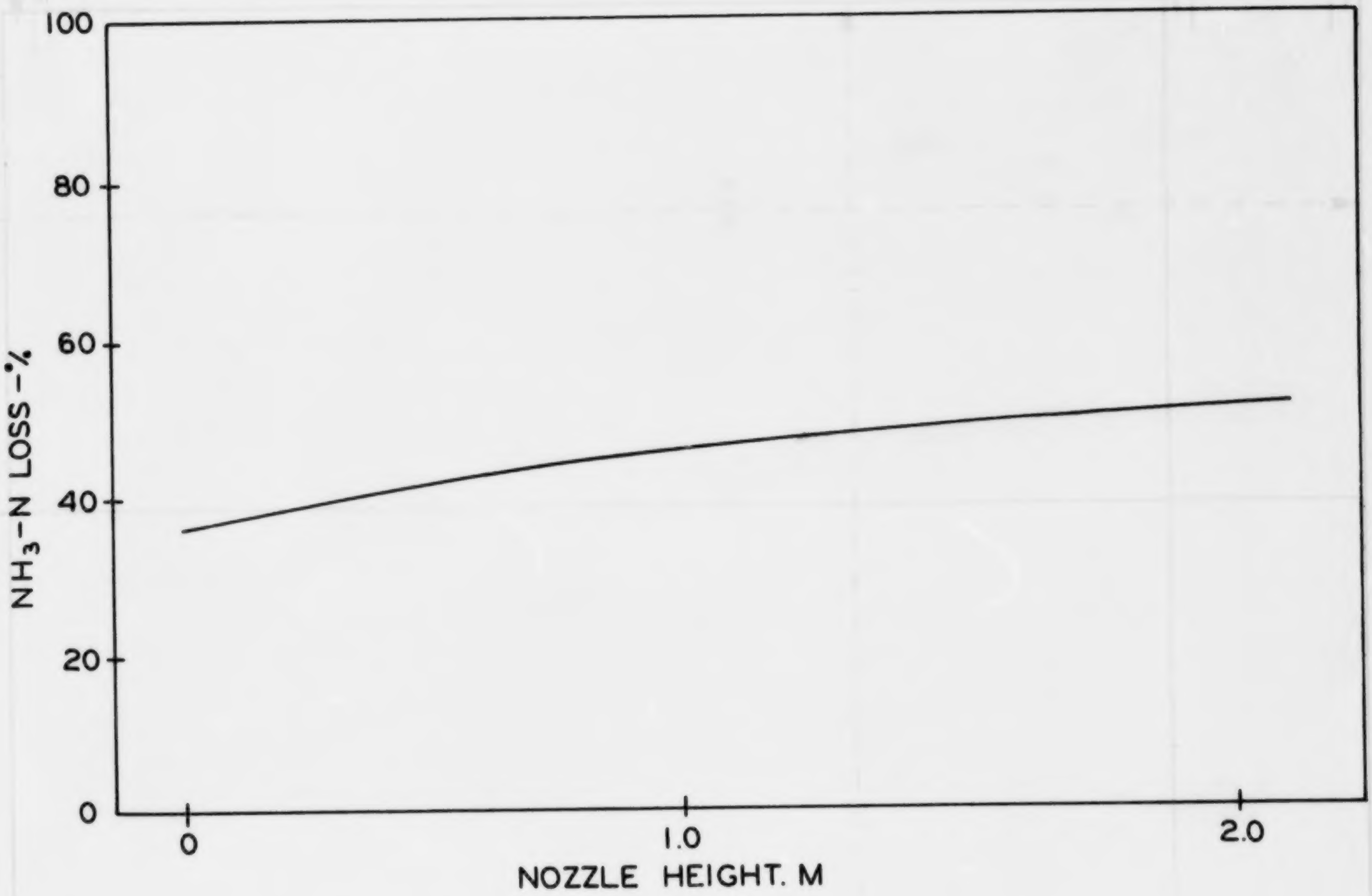

Figure 42. Predicted relationship of NH_3-N loss to nozzle height at pH of 9.

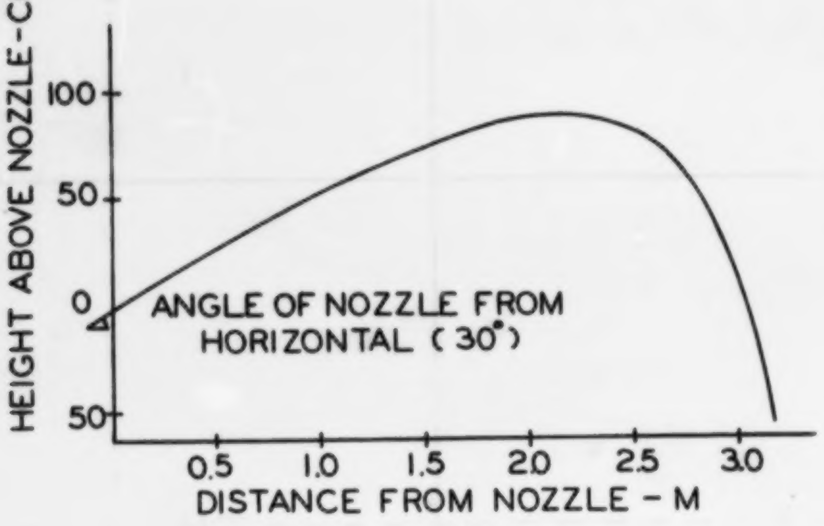

Figure 43. Droplet trajectory as predicted by computer model (average droplet).

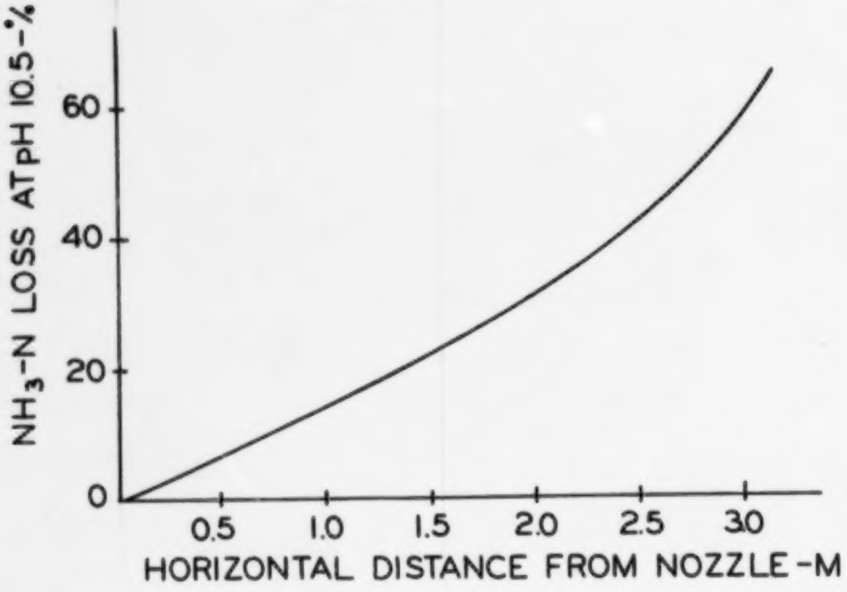

Figure 44. Predicted variation of NH_3-N loss with distance travelled from nozzle (average droplet).

dependent on the distance travelled than on the velocity at which it is travelled.

Since the driving force for NH_3-N volatilization is the concentration gradient between the droplet and the air, the total NH_3-N loss predicted for the droplet flight is dependent on the original concentration, i.e., high concentrations of NH_3-N yield high losses, low concentrations yield low losses. However, losses expressed in terms of percent NH_3-N lost of the original amount proved to be independent of the original concentration of NH_3-N.

The system used for data collection functioned in a very limited segment of the model's total capacity for predictions. The pH remained relatively constant at a value of 7.0; note (Figures 40 and 41) the limits this places on NH_3-N loss. Concentrations of NH_3-N averaged around 100 mg/ℓ, and even the best suggested methods of measuring NH_3-N concentration at this level have an accuracy of no more than 0.5 mg/ℓ. This accuracy was improved on by increasing the number of duplicates run and decreasing the concentration of the acid used for titration.

Figure 45 shows the model's prediction for the NH_3-N loss in the "near" spray as it varies with temperature. Line a) shows the computer predicted losses, line b) the best fit of all data points, and line c) the best fit of data points deleting the seven circled "outlying" points. Although the computer predicted relationship between temperature and percentage NH_3-N loss is not linear, it is extremely close, and statistical data analysis is based on linearity. Line b), best fit of data points was the result of least squares analysis, considering all points. In the case of line c), the seven circled outlying data points were deleted, and the least squares analysis used again. For line b), r^2 is equal to 0.0085; for line c), r^2 equals 0.0175, indicating a low correlation.

The line of best fit through the data does not vary significantly statistically from the predicted line. Unfortunately, due to low slope and high scattering, neither is it significantly different from a line of zero slope: no change with temperature. It is questionable whether this statistical approach provides meaningful analysis of the model. Comparing Figure 45 with Figure 40, it is apparent that the data coincides with predictions within 0.40 percent, the limits of the analysis method. Scattering is, therefore, within the predicted range and the low slope is inherent in the model.

In Figure 46, the model predictions and data points obtained in the analysis of the "far" spray are shown. Note that the data points are far more scattered than the "near" ones. With a fivefold increase in number of collectors, and a corresponding reduction of sample volume in each, errors due to evaporation, residual

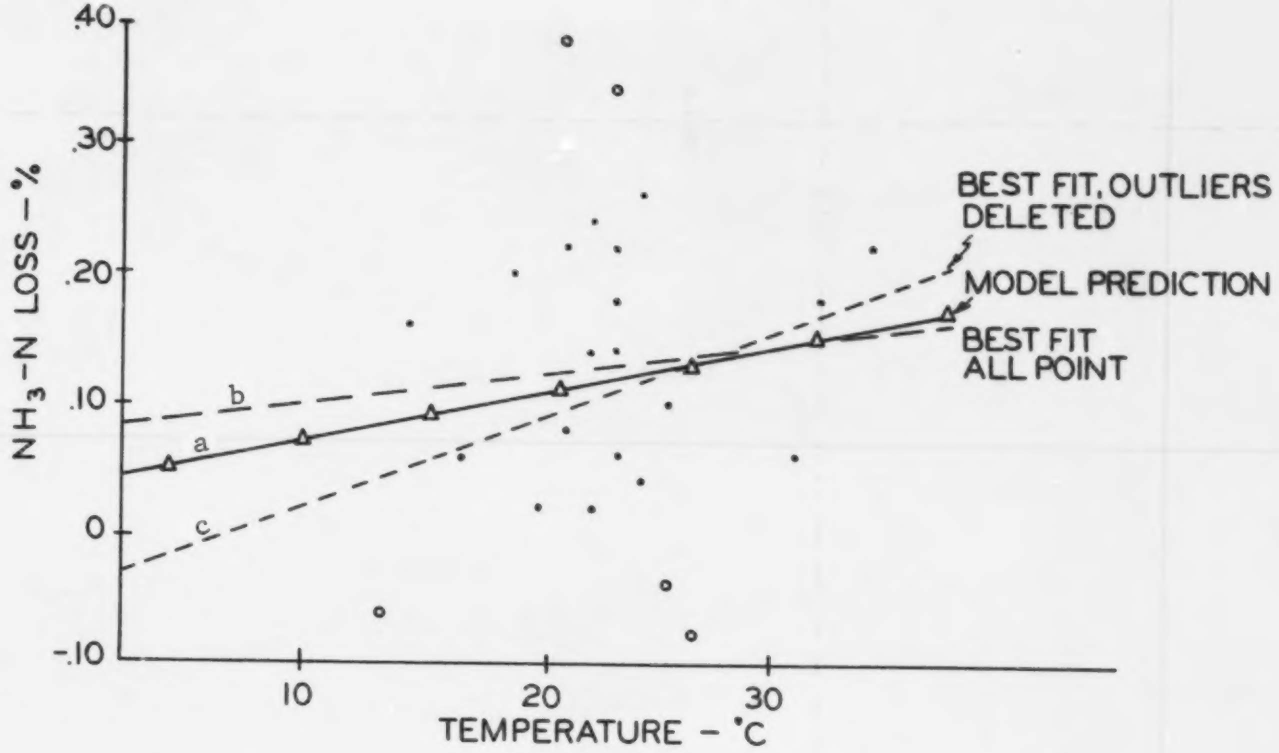

Figure 45. NH_3-N loss in short-distance, small droplets ("near" spray).

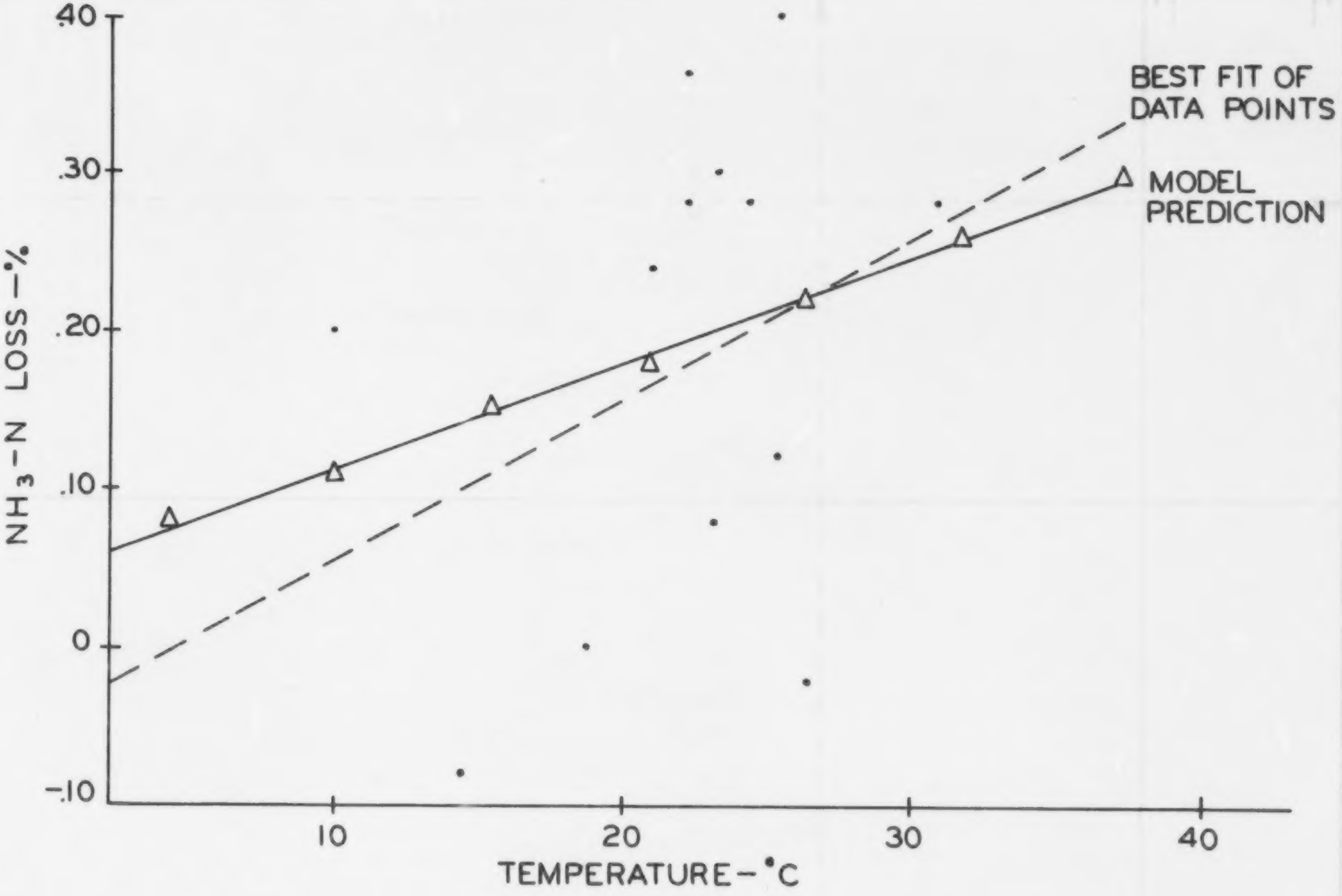

Figure 46. NH_3-N loss in long-distance, large droplets ("far" spray).

TYPING GUIDE SHEET

moisture left in the collectors, trapped insects, and the dilution effects of the added acid would be correspondingly increased. Construction of the graph required deletion of over one-third of the data points as completely meaningless, but the remainder still show an r^2 value less than 0.001, and no significant statistical difference from either the theoretical line or a horizontal one. Again, from a broader viewpoint, two-thirds of the data points matched predictions to within 0.50 percent.

Confirmation of variation of loss with pH comes from two sources: on the theoretical level, English (1974) found that for NH_3-N loss from land applied sludges,

$$N_A = K_G P_{A,S} \qquad (120)$$

and

$$P_{A,S} = \frac{(TAN_{(aq)})\,\gamma_{NH_3}}{K_S\left[1 + \dfrac{\gamma_{NH_3}\,10^{-pH}}{\gamma_{NH_4^+}\,K_a}\right]} \qquad (121)$$

where:

N_A = flux rate of NH_3-N (kg/m^2-hr)

K_G = convective mass transfer coefficient (kg/m^2-hr-atm)

$P_{A,S}$ = equilibrium partial pressure of NH_3-N at the interface (atm)

$(TAN_{(aq)})$ = total aqueous ammonical nitrogen (kg/m^3)

γ_{NH_3} = activity coefficient of NH_3-N (dimensionless)

K_S = solubility constant of NH_3-N (kg/m^3-atm)

$\gamma_{NH_4^+}$ = activity coefficient of NH_3-N ion (dimensionless)

K_a = acid dissociation constant of NH_3-N (dimensionless)

Combining the two formulas and assuming activity coefficients equal to unity, an assumption more true (within 5 percent) in this dilute solution than in sludge, yields the relationship:

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

$$N_A \alpha \frac{1}{[1 + \frac{10^{-pH}}{K_a}]} \qquad (122)$$

This is the same as the factor by which the NH_3-N loss was multiplied to allow for pH impacts in the model

$$s = \frac{1}{[\log^{-1} (pKa-pH) + 1]} \qquad (123)$$

The data infer that a similar approach to predicting NH_3-N loss variation with pH in falling droplets is valid.

Confirmation of the model's prediction of NH_3-N losses at high pH can also be found in the data collected by Jackson, Alban, and Wolfe (1959) and by Henderson, Bianchi, and Doreen (1955), who made no attempt to model losses, but whose data points agree closely with the proposed model.

Separate analyses were performed on the potential pollutants listed in Table 10. These analyses were performed according to suggested procedures with no special efforts being made to increase the precision or accuracy above the inherent abilities of the particular method. As a result, the values show more scatter, and in none was there a significant reduction in concentration during spraying.

TABLE 10. AVERAGE PERCENT CHANGE IN WASTE PARAMETERS DURING SPRINKLING

Parameter	Average Value	Average Percent Loss	Standard Deviation of Percent Loss
TKN	124 mg/ℓ	+1.23	3.01
COD	603 mg/ℓ	-0.32	4.13
PO_4-P	61 mg/ℓ	+0.02	1.61
TDS	398 mg/ℓ	-1.01	5.32
VDS	152 mg/ℓ	-0.17	2.15
TSS	123 mg/ℓ	+0.26	13.40
VSS	110 mg/ℓ	+0.32	17.30

The experimental set-up was designed to test conditions as they actually existed. In this case, those conditions included a relatively low pH and therefore almost negligible NH_3-N losses. In most animal waste management systems the pH will not rise much above the 7-8 range, and the NH_3-N losses should, therefore,

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

not exceed 5 percent due to absence of un-ionized NH_3-N. If the pH is higher, droplets smaller, their velocity greater than usual, or should wind exist, the NH_3-N loss could dramatically increase. The program has the capability of modeling such conditions.

There are particular weaknesses in the program. The effects of wind drift on NH_3-N and water loss in actual field situations is still unknown. For the purposes of this program, it was assumed that wind drift droplets behave as larger ones, so that any droplets moving for greater distances still reach the ground. If such is not the case, the program must be revised. To avoid this conflict, data from tests conducted at wind speeds above 7 km/hr (4 mph) were discounted.

The program also assumes that the spray is ejected as spherical droplets. In fact, for the standard agricultural sprinkler the spray emerges as a stream which, as it travels, is broken up into droplets by the turbulence of its flight; these droplets quickly become spherical. Likewise, the program assumes that an "average droplet" describes the whole spray. Whether or not the simplified model can adequately predict what the actual losses will be can only be determined by further testing.

One major fallacy existed in the method of testing the theory. It was decided at the outset that data should be collected in the field, so the model would describe existing conditions. Although the program was designed to describe NH_3-N losses in agricultural spraying of animal wastes, it would have been more informative to have first laboratory tested the program. This would have allowed greater manipulation of the variables (pH and temperature especially) and could have been used to increase the slope and decrease the relative scatter of data points. Thus, the model should be tested under more extreme conditions to assure its adequate performance under those conditions.

SECONDARY EXPERIMENTATION

Coliform Counts

Five sample series were analyzed for TC before and after travel through the irrigation system. After irrigation and continuous sampling for a period of 1½ hours, samples were transported to the laboratory for immediate analysis. The method of analysis was the membrane filter (MF) technique using Millipore equipment and suggested methods (APHA, 1976). Results were as follows:

Average count (prior to spraying)	8.9×10^6 per 100 ml
Average loss during spraying	8.8 percent
Standard deviation	8.5 percent

EPA-287 (Cin.)
(4-75)

Although the data seem to indicate a slight reduction in coliform count during irrigation, the comparatively small change, combined with the limited accuracy of the method, render the difference insignificant. More sample runs and more duplicates might detect a reduction, but such an effort would be of questionable value since 1) there is nothing in the literature to indicate losses in coliform should occur during sprinkling and 2) at these levels, a 10 percent reduction in coliform has no practical significance. Table 11 shows actual data collected during this study.

TABLE 11. TC CHANGES DURING SPRAYING: RAW DATA

Date	Concentration at Source TC/100 ml		Concentration in Field Collectors TC/100 ml	
	Primary	Duplicate	Primary	Duplicate
9/15	8.4×10^6		11.4×10^6	8.6×10^6
9/18	9.2×10^6	11.1×10^6	8.6×10^6	8.6×10^6
9/19	9.1×10^6	8.3×10^6	6.6×10^6	3.7×10^6
9/20	7.6×10^6	7.3×10^6	6.4×10^6	6.6×10^6
9/21	9.6×10^6	13.0×10^6	9.1×10^6	8.9×10^6

Effect of Herbage on NH_3-N Losses

An approximation of NH_3-N losses from the time the spray strikes the grass, until it reaches the ground was made according to the following method. Using the same samplers, the funnel was filled to a height of 5 cm (2 in) with shredded cellophane in the form known as "Easter grass." Immediately adjacent to each packed sampler was placed a standard sampler. Both were acidified with a few drops of acid in the bottom. After 1½ hours of collecting, the samples were analyzed as usual for NH_3-N.

Results showed a notable difference between samples with grass and samples without, although not enough samples were collected for statistical significance. Samplers with grass showed an average loss of 10.7% NH_3-N as compared to those without grass with a standard deviation of 3.2 percent. Table 12 lists collected data.

TYPING GUIDE SHEET

There was a tendency for the "grass" to pack down enough to cause the liquid to puddle, and there was some splash from droplets lost.

TABLE 12. NH_3-N CONCENTRATION WITH HERBAGE

Date	Source (mg/ℓ)	Collector Without Grass (mg/ℓ)	Collector With Grass (mg/ℓ)
9/15	110.81	110.21	103.41
9/18	98.50	98.40	89.64
9/19	103.02	102.39	88.44
9/20	108.86	108.90	93.87
9/21	116.22	115.31	102.96

EPA-287 (Cin.)
(4-76)

REFERENCES

APHA. 1976. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C.

Dickey, E. C. and D. H. Vanderholm. 1976. Final Report: Feedlot Runoff Research Program. Agricultural Engineering Department, University of Illinois at Urbana-Champaign. Illinois Institute for Environmental Quality Doc. No. 76/08. 56 pp.

English, C. J. 1979. Determination of Equilibrium Partial Pressure of Ammonia Gas above Anaerobically Digested Sewage Sludge. M.S. Thesis, Oregon State University, Corvallis, Oregon.

Frost, K. R. and H. C. Schwalen. 1956. Sprinkler Irrigation Losses. Agricultural Engineering. 36:526-528.

Goering, C. E., L. E. Bode, and M. R. Gebhart. 1975. Mathematical Modeling of Spray Droplet Deceleration and Evaporation. Trans. of the ASAE. 220-225.

Henderson, D. W., W. C. Bianchi, and L. D. Doreen. 1955. Ammonia Losses from Sprinkler Jets. Agricultural Engineering.

Hirschfelder, J. O., R. B. Bird, and E. L. Spotz. 1949. "Diffusion Coefficients for Gas Pairs. Chemical Reviews. 44: 205-231.

Jackson, T. L., L. A. Alban, and J. W. Wolfe. 1959. Ammonia Nitrogen Loss from Sprinkler Applications. Circular of Information 593. Agricultural Experiment Station, Oregon State University, Corvallis, Oregon.

King, H. W., C. O. Wisler, and J. G. Woodburn. 1953. Hydraulics, 5th Ed. John Wiley and Sons, Inc., New York.

Koelliker, J. K. and J. R. Miner. 1973. Desorption of Ammonia From Anaerobic Lagoons. Trans. of the ASAE. 16:148-151.

Kohl, R. A. 1974. Drop Size Distribution from Medium Sized Agricultural Sprinklers. Trans. of the ASAE. 17:690-693.

Laws, J. O. and D. A. Parsons. 1943. The Relationship of Raindrop Size to Intensity. Trans. Am. Geophys. Union. 24:452-460.

Lewis, W. K. and W. G. Whitman. 1924. Resistances to Mass Transfer Across an Interface. Ind. Eng. Chemistry. 16: 1215-1219.

Manges, H. L., R. I. Lipper, L. S. Murphy, W. L. Powers, and L. A. Schmid. 1975. Treatment and Ultimate Disposal of Cattle Feedlot Wastes. EPA-660-2-75-013, U.S. Environmental Protection Agency, Washington, D.C. 136 pp.

Marshall, W. R. 1954. Atomization and Spray Drying. Chem. Engr. Progress Monograph. Series No. 2, Vol. 50. American Institute of Chemical Engineers, New York.

Meyer, L. D. 1958. An Investigation of Methods for Simulating Rainfall on Standard Runoff Plots and a Study of the Drop Size, Velocity, and Kinetic Energy of Selected Spray Nozzles. Special Report No. 81, ARS, USDA, 43 pp.

Miner, J. R. 1967. Water Pollution Potential of Cattle Feedlot Runoff. Ph.D. Thesis, Kansas State University, Manhattan, Kansas (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Michigan). 147 pp.

Miner, J. R., R. I. Lypper, L. R. Fina, and J. W. Funk. 1966. Cattle feedlot runoff--its manure and variation. Journal Water Pollution Control Fed. 38:1582-1591.

Mitchell, J. K. and E. C. Dickey. 1973. Device for Obtaining Water Samples From Small Ponds or Lagoons. Trans. of the ASAE. 16:544-545.

Miyamoto, S. J. Ryan and J. L. Stroehlein. 1975. Sulfuric Acid for the Treatment of Ammoniated Irrigation Water: Reducing Ammonia Volatilization. Soil Sci. Soc. Amer. Proc. 39:544-549.

Ranz, W. E. and W. R. Marshall. 1952a. Evaporation from Drops, Part I. Chem. Engr. Progress. 48:141-146.

Ranz, W. E. and W. R. Marshall. 1952b. Evaporation from Drops, Part II. Chem. Engr. Progress. 48:173-180.

Roessler, J. F., R. Smith, and R. G. Eilers. 1971. Simulation of Ammonia Stripping from Wastewater. Jour. Sanitary Engr. Div. Proceedings of the ASCE. 269-286.

Seginer, I. 1971. Water Losses During Sprinkling. Trans. of the ASAE. 14:656-659.

Smith, M. R. 1970. Analog Simulation of In-Flight Evaporation of Spray Droplets. Trans. of the ASAE. 13:587-590.

Sprinkler Irrigation Association. 1975. Sprinkler Irrigation. Sprinkler Irrigation Assoc., Silver Springs, Maryland.

Stephen, H. and T. Stephen. 1963. Solubilities of Inorganic and Organic Compounds, Vol. 1, Pt. 1. Pargamon Press, Oxford, England.

Welty, J. R., C. E. Wicks, and R. E. Wilson. 1976. Fundamentals of Momentum, Heat and Mass Transfer. John Wiley and Sons, New York.

Zovne, J. J. and J. K. Koelliker. 1979. Application of Continuous Watershed Modeling to Feedlot Runoff Management and Control. EPA-600/2-79-065, U.S. Environmental Protection Agency, Washington, D.C. 156 pp.

APPENDIX A

PREVIOUSLY AVAILABLE CATTLE FEEDLOT RUNOFF DATA

TABLE A-1. BOD_5 CONCENTRATIONS IN RUNOFF FROM A DIRT EXPERIMENTAL CATTLE FEEDLOT IN KANSAS DURING VARIOUS SEASONS OF 1965. (MINER, 1967)

Season	BOD_5 Concentration, mg/ℓ
Winter	
Typical	250
Range	150-350
Spring and Fall	
Typical	450
Range	350-550
Summer	
Typical	650
Range	550-750

TABLE A-2. NH_3-N CONCENTRATIONS IN RUNOFF FROM A CONCRETE AND A DIRT EXPERIMENTAL CATTLE FEEDLOT IN KANSAS. (mg/l) (MINER, 1967)

	Concrete Lot		Dirt Lot	
Season	NH_3-N Concentration mg/ℓ	NH_3-N TKN	NH_3-N Concentration mg/ℓ	NH_3-N TKN
Summer	50-139	0.10-0.4	26-62	0.1-0.3
Fall	20-77	0.3-0.20	13-45	0.06-0.2
Winter	1.3-7.0	0.01-0.05	1.0-3.8	0.02-0.6

TABLE A-3. NO_3-N CONCENTRATIONS IN RUNOFF FROM A CONCRETE AND A DIRT CATTLE FEEDLOT IN KANSAS DURING TWO SEASONS OF 1965. (MINER, 1967)

	NO_3-N Concentrations, mg/ℓ	
Feedlot Surface	July-August	October-November
Concrete	1.0-6.0	1.0-5.0
Dirt	1.0-7.0	1.0-23

TABLE A-4. TSS CONCENTRATIONS IN RUNOFF FROM A CONCRETE AND A DIRT EXPERIMENTAL CATTLE FEEDLOT IN KANSAS IN 1965. (MINER, 1967)

Lot Condition and Rainfall Intensity	TSS, mg/ℓ Concrete Lot	 Dirt Lot
Warm weather (July-Aug.)		
Moist lot 1 in/hr	6,000	5,000
Dry lot 0.4 in/hr	3,000	1,500
Dry lot 2.5 in/hr	1,400	2,000
Wet lot 2.5 in/hr	3,000	3,000
Wet lot 0.3 in/hr	12,000	10,500
Cool weather (Oct.-Nov.)		
Wet lot 1.0 in/hr	2,000	1,800
Wet lot 0.5 in/hr	2,500	---

TABLE A-5. NO_2-N CONCENTRATIONS IN RUNOFF FROM A CRNCRETE AND A DIRT EXPERIMENTAL CATTLE FEEDLOT IN KANSAS DURING TWO SEASONS OF 1965. (MINER, 1967)

Feedlot Surface	NO_2-N Concentration, mg/ℓ July-August	 October-November
Concrete	0.1-11	0.4-2.3
Dirt	0.1-6.0	0.5-2.6

TABLE A-6. DENSITIES OF TC, FC, AND FS IN RUNOFF FROM A CONCRETE EXPERIMENTAL CATTLE FEEDLOT IN KANSAS DURING JULY THROUGH NOVEMBER 1965. (MINER, 1967)

Bacteria Counted	Millions of Organisms per 100 ml, MPN*				
	No. Values	Maximum	Minimum	Median	70% Limits
TC	47	790	3.3	130	33-348
FC	49	790	3.3	130	35-240
FS	43	790	3.3	79	13-240

* MPN = most probable number.

TABLE A-7. DENSITIES OF TC, FC, AND FS IN RUNOFF FROM A DIRT EXPERIMENTAL CATTLE FEEDLOT IN KANSAS DURING JULY THROUGH NOVEMBER 1965. (MINER, 1967)

Bacteria Counted	Millions of Organisms per 100 ml, MPN*				
	No. Values	Maximum	Minimum	Median	70% Limits
TC	49	790	4.8	79	22-348
FC	49	542	3.3	33	8-79
FS	49	542	4.0	24	8-79

* MPN = most probable number.

TABLE A-8. BOD_5 CONCENTRATIONS IN RUNOFF FROM A CONCRETE EXPERIMENTAL CATTLE FEEDLOT IN KANSAS DURING VARIOUS SEASONS OF 1965. (MINER, 1967)

Season	BOD_5 Concentration, mg/ℓ
Winter	
Typical	450
Range	300-600
Spring and Fall	
Typical	900
Range	750-1,050
Summer	
Typical	1,300
Range	1,100-1,400

TABLE A-9. CATTLE FEEDLOT RUNOFF CHARACTERISTICS. (LOEHR, 1974)

Location	TS	TVS	COD	BOD_5	TKN	NH_3-N	Total-P	Ref.
	mg/ℓ							
Nebraska								
Snowmelt								
mean			41,000		2,100	780		McCalla et al., (1972)
range			14,100–77,000		190–6,530	6–2,020		
Rainfall								
mean			3,100		920	140		McCalla et al., (1972)
range			1,300–8,200		11–8,590	2–1,240		
Texas								
Dirt lot								
mean			9,500	1,460	128	56		Wells et al., (1972)
range			2,900–28,000	1,010–2,200	9–285	2–85		
Concrete lot								
mean			21,500	8,000	500	350		Wells et al., (1972)
range			8,400–32,800	3,300–12,700	70–1,070	33–775		
Colorado		100–7,000		300–6,000				Norton & Hansen (1969)
Kansas	10,000–25,000		4,000–40,000	1,000–11,000	200–450			Loehr (1970)
Texas	3,100–28,880		1,440–16,320	1,075–3,450		4–173		Kreis et al., (1972)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

TABLE A-10. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A CONCRETE SURFACED LOT NEAR LUBBOCK, TEXAS ON WHICH CATTLE WERE FED ROUGHAGE-CONCENTRATE RATION. (WELLS ET AL., 1972)

Date	pH	BOD_5 (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
8-24-69	6.70	10,067	28,450	875	519	300	2,104
6-26-69	6.15	8,500	32,800	320	515	384	2,056
9-9-69	6.62	12,750	32,172	97	774	301	2,402
9-22-69	6.75	5,270	11,514	22	100	132	1,632
10-21-69	6.67	10,250	20,868	140	406	114	170
10-26-69	6.85	3,300	8,400	70	33	35	86
11-1-69	7.00	5,566	16,252	0	115	115	336

9-1/8"

TABLE A-11. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A CONCRETE FEEDLOT NEAR LUBBOCK, TEXAS RESULTING FROM A 3.6 CM (1.4 IN) RAINFALL STARTING AT 11:00 P.M. ON AUGUST 24, 1969. (TEXAS TECH. UNIVERSITY, 1971)

Time of Collection	pH	BOD_5 (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
11:35 p.m.	6.60	16,800	48,000	625	525	532	2,595
11:58 p.m.	6.80	6,120	20,451	975	526	315	1,955
12:35 a.m.	6.65	7,400	22,032	1,000	485	36	2,000
2:25 a.m.	6.80	9,950	23,316	900	543	285	1,865

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE A-12. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A CONCRETE SURFACED FEEDLOT NEAR LUBBOCK, TEXAS ON WHICH CATTLE WERE FED AN ALL-CONCENTRATE RATION. (TEXAS TECH. UNIVERSITY, 1971)

Date	pH	BOD$_5$ (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
8-24-69	6.30	7,355	28,929	1,270	340	610	1,030
8-26-79	5.90	8,900	38,400	280	395	302	1,584
9-9-69	5.60	10,400	30,230	228	518	797	1,174
9-22-69	6.90	4,424	10,080	36	460	650	1,380
10-21-69	6.35	8,300	20,742	386	304	293	116
10-26-69	6.70	12,000	23,000	350	140	235	236
11-1-69	7.30	2,395	4,971	0	120	250	116

TABLE A-13. AVERAGE CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A DIRT LOT NEAR LUBBOCK, TEXAS ON WHICH CATTLE WERE FED ROUGHAGE-CONCENTRATE RATION. (TEXAS TECH. UNIVERSITY, 1971)

Date	pH	BOD$_5$ (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
8-24-69	7.68	1,758	8,280	103	79	200	1,238
8-26-69	7.40	1,010	2,964	24	77	25	928
9-9-69	7.70	1,340	6,316	3	75	50	856
9-22-69	7.63	1,400	28,000	3	71	40	1,400
10-21-69	7.50	1,620	4,400	28	85	67	99
10-26-69	7.45	1,100	8,000	0	2	6	183
11-1-69	7.70	2,200	8,795	0	3	117	436

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin)
(4-76)

TABLE A-14. CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A DIRT LOT NEAR LUBBOCK, TEXAS RESULTING FROM PRECIPITATION STARTING AT 11:00 P.M. ON AUGUST 24, 1969. (TEXAS TECH. UNIVERSITY, 1971)

Time of Collection	pH	BOD_5 (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
11:35 p.m.	7.80	1,630	5,450	16	51	27	1,002
11:58 p.m.	7.50	2,500	9,781	128	98	297	1,092
12:35 a.m.	7.60	1,275	6,240	132	100	434	1,238
2:25 a.m.	7.80	1,630	11,650	136	67	44	1,620

TABLE A-15. AVERAGE CONCENTRATIONS OF POLLUTANTS IN RUNOFF FROM A DIRT LOT NEAR LUBBOCK, TEXAS ON WHICH CATTLE WERE FED AN ALL-CONCENTRATE RATION. (TEXAS TECH. UNIVERSITY, 1971)

Date	pH	BOD_5 (mg/ℓ)	COD (mg/ℓ)	NO_3-N (mg/ℓ)	NH_3-N (mg/ℓ)	Org-N (mg/ℓ)	Total Alk. (mg/ℓ)
8-24-69	7.95	1,400	5,160	163	48	118	955
8-26-69	7.15	1,350	7,212	96	48	33	1,602
9-9-69	7.62	1,145	6,220	6	83	25	864
9-22-69	7.30	1,580	4,817	62	75	20	746
10-24-69	7.35	1,390	4,042	24	50	22	70
11-1-69	7.10	3,210	9,942	0	30	17	360

TABLE A-16. QUALITY OF RUNOFF FROM STEEP NON-PAVED CATTLE FEEDLOTS (HAMILTON STANDARD, 1973)

ANIMAL TYPE: Beef Cattle
ANIMAL WEIGHT: 800 lbs avg.
TYPE OF WASTE: Dirt-Steep Slope-Runoff
AREA: 200 ft^2/head

	lb/head/inch Runoff			mg/ℓ		
Parameter	Minimum	Average	Maximum	Minimum	Average	Maximum
Total wet solids	-	1196.0		-	-	-
Moisture	1186.0	1186.0	1190.0	982,750	990,800	990,800
TS	9.57	9.57	17.9	9,200	9,200	17,250
TVS	4.78	4.54	9.57	4,370	4,600	9,200
SS	1.20	2.99	5.98	1,150	2,875	5,750
pH*	5.1	7.6	9.4			
BOD_5	1.20	1.79	7.18	1,150	1,725	5,750
COD	3.59	4.19	35.9	3,450	4,025	23,000
Ash	2.39	5.03	8.97	2,300	4,830	8,625
TKN	0.023	0.184	1.31	23	173	1,265
NH_3-N	0	0.069	0.598	0	69	575
NO_3^--N	0	0.0345	0.0265	0	29	138
Total-P	0.0115	0.104	0.253	16	92	230
Total-K	0.0230	0.403	1.04	23	391	1,035
Mg^{++}	0.0805	0.115	0.138	81	109	138
Na^+	0.0805	0.276	0.805	75	265	805

* pH expressed as log hydrogen ion concentration.

TABLE A-17. QUALITY OF RUNOFF FROM NON-PAVED CATTLE FEEDLOTS. (HAMILTON STANDARD, 1973)

ANIMAL TYPE: Beef Cattle
ANIMAL WEIGHT: 800 lbs avg.
TYPE OF WASTE: Dirt-Normal Slope-Runoff
AREA: 200 ft^2/head

Parameter	lb/head/inch Runoff			mg/ℓ		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Total wet solids	-	1040.0	-	-	-	-
Moisture	1031.7	1031.7	1034.4	985,000	992,000	992,000
TS	8.32	8.32	15.6	8,000	8,000	15,000
TVS	3.95	4.16	8.32	3,800	4,000	8,000
SS	1.04	2.6	5.20	1,000	2,500	5,000
pH*	5.1	7.6	9.4			
BOD_5	1.04	1.56	6.24	1,000	1,500	5,000
COD	3.12	3.64	31.2	3,000	3,500	20,000
Ash	2.08	4.37	7.8	2,000	4,200	7,500
TKN	0.02	0.16	1.14	20	150	1,100
NH_3-N	0	0.06	0.52	0	60	500
NO_3-N	0	0.03	0.023	0	25	120
Total-P	0.01	0.08	0.22	14	80	200
Total-K	0.02	0.35	0.9	20	340	900
Mg^{++}	0.07	0.10	0.12	70	95	120
Na^+	0.07	0.24	0.7	65	230	700

* pH expressed as log hydrogen ion concentration.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-78)

TABLE A-18. QUALITY OF RUNOFF FROM PAVED CATTLE FEEDLOTS. (HAMILTON STANDARD, 1973)

ANIMAL TYPE: Beef Cattle
ANIMAL WEIGHT: 800 lbs avg.
TYPE OF WASTE: Paved Lot Runoff
AREA: 50 ft^2/head

	lb/head/inch Runoff			mg/ℓ		
Parameter	Minimum	Average	Maximum	Minimum	Average	Maximum
Total wet solids	-	260.0	-	-	-	-
Moisture	256.88	255.84	254.8	980,000	984,000	988,000
TS	3.18	4.16	5.2	12,000	160,000	20,000
TVS	1.56	2.16	3.12	6,000	8,300	12,000
SS	0.52	1.56	2.6	2,000	6,000	10,000
pH*	5.5	6.6	7.5			
BOD_5	0.52	0.83	3.12	2,000	3,200	12,000
COD	1.3	1.85	10.4	5,000	7,100	40,000
Ash	1.04	2.00	3.9	4,000	7,700	15,000
TKN	0.1	0.29	0.41	370	1,100	1,580
NH_3-N	0.026	0.08	0.13	100	325	500
NO_3-N	0	0.09	0.312	0	360	1,200
Total-P	0.01	0.03	0.08	20	110	305
Total-K	0.01	0.09	0.42	30	350	1,600
Mg^{++}	0.02	0.03	0.03	80	100	140
Na^+	0.03	0.12	0.25	120	450	950

* pH expressed as log hydrogen ion concentration.

TABLE A-19. RUNOFF QUALITY FROM A 0.4 HA (1 AC) PAVED CATTLE FEEDLOT IN EAST-CENTRAL ILLINOIS COLLECTED NOVEMBER 4, 1974 FOLLOWING A 1.25 CM (0.5 IN) RAINFALL

Time after runoff began hr.	NH_3-N mg/ℓ	TKN mg/ℓ	TS mg/ℓ	EC mhos	Total P mg/ℓ	Total K mg/ℓ	Na^+ mg/ℓ
1	62	234	7006	2300	52	683	12
2	missing						
3	72.7	379	9360	2200	58	645	8
4	71.3	380	7628	1900	64	557	7
5	62.0	370	9554	1900	63	528	9
6	77	342	5450	1800	78	594	8
7	87.7	473	9632	2300	82	732	12
8	141	460	8314	2550	82	756	12
9	111	323	5554	2550	77	700	10

Source: D. H. Vanderholm, personal communication, November 16, 1977.

TABLE A-20. CONCENTRATIONS OF SELECTED IONS IN RUNOFF FROM BEEF CATTLE FEEDYARDS. (CLARK ET AL., 1975)

Location	Na^+ mg/ℓ	Ca mg/ℓ	Mg^{++} mg/ℓ	K mg/ℓ	Cl^- mg/ℓ
Bellville, TX	230	---	---	340	410
Bushland, TX	588	449	199	1,320	1,729
McKinney, TX	408	698	69	761	450
Mead, NE	478	181	146	1,864	700
Pratt, KS	511	166	110	815	---

TABLE A-21. AVERAGE CHEMICAL CHARACTERISTICS OF RUNOFF FROM BEEF CATTLE FEEDYARDS. (CLARK ET AL., 1975)

Location	TS mg/ℓ	EC m mhos/cm	COD mg/ℓ	Total-N mg/ℓ	Total-P mg/ℓ
Bellville, TX	9,000	---	4,000	50	85
Bushland, TX	15,300	8.4	15,700	1,083	205
Ft. Collins, CO	17,500	8.6	17,800	1,153	93
McKinney, TX	11,429	6.7	7,210	228	69
Mead, NE	15,200	3.2	3,100	854	300
Pratt, KS	7,500	5.4	5,000	180	50
Sioux Falls, SD	2,986	---	2,160	145	47

TABLE A-22. GENERAL INFORMATION FOR EACH BEEF CATTLE FEEDYARD FROM WHICH DATA WERE REPORTED IN TABLES A-20 and 21

Location	Researcher	Years of Study	Ares ha	Average Slope %	Stocking Rate m^2/animal	Annual Precipitation cm	Annual Evaporation cm	Moisture Deficit cm
Bellville, TX	Reddell*	72	7.5	3.0	35	110	135	25
Bushland, TX	Clark†	71-73	4.0	1.5	12	50	165	115
Ft. Collins, CO	Duke‡	69-71	0.4	6.0	19	40	100	60
Gretna, NE	Swanson§	68-72	0.3	6.0	46	70	110	40
McKinney, TX	Kreis#	69-70	13.0	3.0	9	90	140	50
Mead, NE	Gilbertson**	68-72	0.1	3,6,9	19	70	110	40
Pratt, KS	Manges††	69-70	13.3	1.3	33	60	150	90
Sioux Falls, SD	Dornbush‡‡	70-71	1.6	3.0	53	60	90	30

* Reddell and Wise, 1974.
† Clark, Schneider and Stewart, 1974.
‡ Clark, Gilbertson and Duke, 1975.
§ Swanson, et al., 1971.
# Kreis, Scalf and McNabb, 1972.
** McCalla, et al., 1972.
†† Manges, Schmid and Murphy, 1971.
‡‡ Dornbush and Madden, 1973.

TABLE A-23. SUMMARY OF INFORMATION AND AVERAGE RUNOFF QUALITY FROM EIGHT GREAT PLAINS BEEF FEEDLOTS. (CLARK ET AL., 1975)

Characteristic	Bellville Texas	Bushland Texas	Fort Collins Colorado	Gretna Nebraska
Researcher	Reddell*	Clark†	Duke‡	Swanson§
Years of study	72	71-73	69-71	68-72
Feedlot area, ha	7.5	4.0	0.4	0.3
Feedlot slope, %	3.0	1.5	6.0	6.0
Stocking rate, No./ha	35	12	19	46
Average annual precipitation, cm	110	50	40	70
Average annual evaporation, cm	135	165	100	110
Moisture deficit, cm	25	115	60	40
TS, mg/ℓ	9,000	15,300	17,500	--
EC, m mhos/cm	--	8.4	8.6	--
COD, mg/ℓ	4,000	15,700	17,800	--
TKN, mg/ℓ	50	1,083	1,153	--
Total-P, mg/ℓ	85	205	93	--
Na^{+}, mg/ℓ	230 110 25	588 50 115	--	--
CA^{++}, mg/ℓ	--	449	--	--
Mg^{++}, mg/ℓ	--	199	--	--
K^{+}, mg/ℓ	340	1,320	--	--
Cl^{-}, mg/ℓ	410	1,729	--	--

(continued)

TABLE A-23 (continued)

Characteristic	McKinney Texas	Mead Nebraska	Pratt Kansas	Sioux Falls South Dakota
Researcher	Kreis#	Gilbertson**	Manges††	Dornbush‡‡
Years of study	69-70	68-72	69-70	70-71
Feedlot area, ha	13.0	0.1	13.3	1.6
Feedlot slope, %	3.0	3,6,9	1.3	3.0
Stocking rate, No./ha	9	19	33	53
Average annual precipitation, cm	90	70	60	60
Average annual evaporation, cm	140	110	150	90
Moisture deficit, cm	50	40	90	30
TS, mg/ℓ	11,429	15,200	7,500	2,896
EC, m mhos/cm	6.7	3.2	5.4	--
COD, mg/ℓ	7,210	3,100	5,000	2,160
TKN, mg/ℓ	228	854	180	145
Total-P, mg/ℓ	69	300	50	47
Na^+, mg/ℓ	69	300	50	47
Ca^{++}, mg/ℓ	698	181	166	--
Mg^{++}, mg/ℓ	69	146	110	--
K^+, mg/ℓ	761	1,864	815	--
Cl^-, mg/ℓ	450	700	--	--

* Reddell and Wise, 1974.
† Clark, Schneider and Stewart, 1974.
‡ Clark, Gilbertson and Duke, 1975.
§ Swanson, et al., 1971.
# Kreis, Scalf and McNabb, 1972.
** McCalla, et al., 1972.
†† Manges, Schmid and Murphy, 1971.
‡‡ Dornbush and Madden, 1973.

REFERENCES FOR APPENDIX A

Clark, R. N., C. B. Gilbertson, and H. R. Duke. 1975. Analysis of Runoff from Southern Great Plains Feedlots. Trans. of the ASAE 18:319-322.

Clark, R. N., A. D. Schneider, and B. A. Stewart. 1974. Analysis of Runoff from Southern Great Plains Feedlots. ASAE Paper 74-4017. American Society of Agricultural Engineers, St. Joseph, Michigan.

Dornbush, J. N. and J. M. Madden. 1973. Pollution Potential of Runoff from Production Livestock Feeding Operations in South Dakota. Report No. A-025-SDAK. South Dakota State University, Brooking, South Dakota.

Hamilton Standard. 1973. Development Document for Effluent Limitations Guidelines and Standards of Performance - Feedlot Industry. 276 pp.

Kreis, R. D., M. R. Scalf, and J. F. McNabb. 1972. Characteristics of Rainfall Runoff from a Beef Cattle Feedlot. Final Report, Proj. 13040 FHP, EPA-R2-72-061. U.S. Environ. Protect. Agency, Washington, D.C. 43 pp.

Loehr, R. C. 1970. Drainage and Pollution from Beef Cattle Feedlots. Jour. Sanit. Eng. Div., Amer. Soc. Civil Eng. 96:SA6, 1295-1309.

Loehr, R. C. 1974. Agricultural Waste Management. Academic Press, New York.

McCalla, T. M., J. R. Ellis, C. B. Gilbertson, and W. R. Woods. 1972. Chemical Studies of Solids, Runoff, Soil Profile and Groundwater from Beef Cattle Feedlots at Mead, Nebraska. Proc. Agr. Waste Manage. Conf., Cornell University, Ithaca, New York. 211-223.

Miner, J. R. 1967. Water Pollution Potential of Cattle Feedlot Runoff. Ph.D. thesis. Kansas State University. 147 pp. (Mic. 67-9147, Univ. Microfilms, Ann Arbor, Michigan).

Norton, T. E. and R. W. Hansen. 1969. Cattle Feedlot Water Quality Hydrology. Proc. Agr. Waste Manage. Conf., Cornell University, Ithaca, New York. 203-216.

Reddell, D. L. and G. G. Wise. 1974. Water Quality of Storm Runoff from a Texas Beef Feedlot. Texas Agr. Expt. Sta. PR-3224. College Station, Texas.

Swanson, N. P., L. N. Miekle, J. C. Larimor, T. M. McCalla, and J. R. Ellis. 1971. Transport of Pollutants from Sloping Cattle Feedlots as Affected by Rainfall Intensity, Duration, and Recurrence. In: Livestock Waste Management and Pollution Abatement. ASAE. pp. 51-55.

Texas Tech. University. 1971. Characteristics of Wastes from Southwestern Cattle Feedlots. U.S. Environmental Protection Agency, Water Pollution Control Series. 13040 DEM 01/71. 87 pp.

Wells, D. M., G. F. Meenaghan, R. C. Albin, E. A. Coleman, and W. Grub. 1972. Characteristics of Wastes from Southwest Beef Cattle Feedlots. In: Waste Management Research, Proceedings of the 1972 Cornell Agricultural Waste Management Conference. 385-404.

APPENDIX B

PREVIOUSLY AVAILABLE CATTLE FEEDLOT RUNOFF RETENTION BASIN QUALITY DATA

TABLE B-1. BOD AND COD CONCENTRATIONS OF A BEEF FEEDLOT RUNOFF RETENTION NEAR MEAD, NEBRASKA. (GILBERTSON ET AL., 1971)

Date*	BOD (mg/ℓ)	COD (mg/ℓ)
5-12-69	578	1,385
5-19-69	570	1,095
5-26-69	450	1,267
6-2-69	430	1,550
6-9-69	570	1,439
6-16-69	780	1,740
6-23-69	380	1,875

* Feedlot runoff resulting from rainfall events was added to the pond May 7, May 21, and June 12, 1969.

TABLE B-2. NUTRIENT CONTENT OF EAST-CENTRAL ILLINOIS HOLDING POND WATER APPLIED TO CROPLAND. (DICKEY AND VANDERHOLM, 1976)

Nutrient	May 14, 1975	Aug. 12, 1975
N, g/m^3	150	93
NH_3-N, percent of TKN	62	20
Total-P, g/m^3	35	18
K, g/m^3	217	372

TABLE B-3. ANALYSES OF MANURE SOLIDS, SETTLING POND SOLIDS, AND HOLDING POND SEDIMENT, EAST-CENTRAL ILLINOIS CATTLE FEEDLOT. (DICKEY AND VANDERHOLM, 1976)

Constituent	Manure Solids	Settling Basins Solids	Holding Pond Sediment
Moisture, percent wet basis	51.2	79.3	84.6
TKN, percent air dry basis	2.81	1.91	2.01
K, percent air dry basis	2.72	1.05	1.23
Na^+, percent air dry basis	0.14	0.08	0.09
Total-P, percent air dry basis	0.63	0.39	0.67
No. of samples	8	11	6

TABLE B-4. AVERAGE FRACTION OF TS IN HOLDING POND WATER THAT WERE SUSPENDED SAMPLES, COLLECTED FROM THREE ILLINOIS CATTLE FEEDLOTS DURING 1974 AND 1975. (DICKEY AND VANDERHOLM, 1976)

Farm Location	TSS/TS 1974	TSS/TS 1975
East-Central Illinois	0.13	0.119
Northeast Illinois	0.088	0.088
Northwest Illinois	0.106	0.085

TABLE B-5. AVERAGE FRACTION OF TKN IN HOLDING POND WATER PRESENT IN NH_3-N FORM. SAMPLES COLLECTED FROM THREE CONCRETE SURFACED CATTLE FEEDLOT WASTE MANAGEMENT SYSTEMS. (DICKEY AND VANDERHOLM, 1976)

Farm Location	NH_3-N/TKN 1974	NH_3-N/TKN 1975
East-Central Illinois	0.44	0.43
Northeast Illinois	0.50	0.42
Northwest Illinois	0.29	0.10

TABLE B-6. BEEF FEEDLOT RUNOFF HOLDING POND COMPOSITION. CONCRETE SURFACED LOT IN NORTHEAST ILLINOIS. (DICKEY AND VANDERHOLM, 1975)

Period	TKN mg/ℓ	Total-P mg/ℓ	K mg/ℓ	Na^+ mg/ℓ	Cl^- mg/ℓ	TS mg/ℓ	COD mg/ℓ	EC m mhos/cm
May-June 1974	100	30	200					
July-Sept 1974	80	30	250					
1974 mean				75	180	1800	1100	1500
1975 mean				75	200	1700	1100	1400

TABLE B-7. BEEF FEEDLOT RUNOFF HOLDING POND COMPOSITION. CONCRETE SURFACED LOT IN NORTHWEST ILLINOIS. (DICKEY AND VANDERHOLM, 1976)

Period	TKN mg/ℓ	Total-P mg/ℓ	K mg/ℓ	Na^+ mg/ℓ	Cl^- mg/ℓ	TS mg/ℓ	COD mg/ℓ	EC m mhos/cm
1974 mean	80	7	75	18	70	800	500	500
1975 mean	100	5	100	30	110	750	500	500

TABLE B-8. BEEF FEEDLOT RUNOFF HOLDING POND COMPOSITION. CONCRETE SURFACED LOT IN EAST-CENTRAL ILLINOIS. (DICKEY AND VANDERHOLM, 1976) SIGNIFICANT RAINFALL IN EARLY MAY, MID-JUNE, MID-AUGUST, AND EARLY SEPTEMBER

Period	NH_3-N mg/ℓ	TKN mg/ℓ	Total-P mg/ℓ	K mg/ℓ	Na^+ mg/ℓ	Cl^- mg/ℓ	TS mg/ℓ	EC m mhos/cm	COD mg/ℓ
Apr-May 1974	175	300	125	200	50	100	3,000	1,800	3,000
Aug-Oct 1974	30	100	125	50	30	50	2,000	1,200	1,000
Nov 1974	150	250	450	125	40	175	4,500		5,000
Apr-Jun 1975		150	35	225	40	90	2,200		
Aug-Oct 1975			30	275	60	150	1,800		

REFERENCES FOR APPENDIX B

Dickey, E. C. and D. H. Vanderholm. 1976. Final Report: Feedlot Runoff Research Program. Agricultural Engineering Department, University of Illinois at Urbana-Champaign. Illinois Institute for Environmental Quality Doc. No. 76/08. 56 pp.

Gilbertson, C. B., T. M. McCalla, J. R. Ellis, O. E. Cross, and W. R. Woods. 1971. Runoff, Solid Wastes, and Nitrate Movement on Beef Feedlots. Jour. Water Poll. Control Fed. 49, 3, 483-493.

APPENDIX C

FIELD DATA FROM FEEDLOT

TABLE C-1. RECORD OF RAINFALL AND VOLUME OF STORED WASTE PUMPED INTO AND OUT OF THE RETENTION BASIN AT THE FIELD SITE

Date	Recorded rainfall in.	Volume of liquid pumped, cu ft	
		Into basin	Out of basin
5-12	0.32	0	0
5-13	0.38	0	0
5-14	0.15	0	0
5-17	0.00	1,800	0
5-20	0.75	0	0
5-23	0.39	0	0
6-7	0.10	0	0
6-8	0.10	0	0
6-15	0.21	0	0
6-18	0.15	0	0
6-20	0.65	0	0
6-25	0.30	0	0
6-26	0.30	0	0
6-28	0.00	1,800	0
7-1	0.05	0	0
7-2	1.20	0	0
7-4	0.00	1,800	0
7-10	0.00	0	6,015
7-11	0.00	0	18,047
7-12	0.00	0	26,736
7-13	2.80	0	6,684
7-23	1.00	0	0
7-27	0.55	0	0
8-2	0.35	0	10,026
8-3	0.00	0	6,689

(continued)

TABLE C-1 (continued)

Date	Recorded rainfall in.	Volume of liquid pumped, cu ft	
		Into basin	Out of basin
8-4	0.00	0	13,368
8-7	0.10	0	0
8-10	0.40	2,005	0
8-11	0.30	0	0
8-16	0.15	0	0
8-17	0.20	0	0
8-24	0.20	0	0
8-28	0.85	0	0
9-17	0.95	0	0
9-21	0.25	0	0
9-30	0.35	0	0
10-3	0.25	0	0
10-5	0.30	0	0
10-11	0.40	0	0
10-25	0.35	0	0

TABLE C-2. RUNOFF RETENTION BASIN TEMPERATURE, pH AND STAFF GAUGE HEIGHT MEASURED AT THE FIELD SITE BETWEEN MAY AND NOVEMBER 1978

Date	Water Temperature °C	pH	Staff Gauge Height, ft.
5-4	10.00	7.00	--
5-8	10.00	7.00	4.95
5-9	10.00	7.00	4.90
5-10	11.00	7.00	4.90
5-11	11.00	7.00	4.90
5-12	12.00	7.10	4.95
5-13	12.00	7.10	4.98
5-14	13.00	7.10	5.02
5-15	14.00	7.10	5.05
5-16	14.00	7.10	5.06
5-17	15.00	7.20	5.10
5-18	15.00	7.20	5.10
5-19	16.00	7.20	5.10
5-20	16.00	7.20	5.15
5-21	17.00	7.20	5.15
5-22	17.00	7.20	5.15
5-23	18.00	7.30	5.17
5-24	18.50	7.30	5.17
5-25	20.00	7.50	5.18
5-26	20.00	7.50	5.18
5-27	20.50	7.20	5.18
5-28	21.00	7.20	5.19
5-29	22.00	7.40	5.19
5-30	20.00	7.20	5.18
5-31	21.00	7.30	5.10
6-1	21.00	7.30	5.08
6-2	21.00	7.30	5.08
6-3	19.00	7.40	5.02
6-4	21.00	7.40	5.02
6-5	22.00	7.50	4.97
6-6	20.00	7.50	4.97
6-7	20.00	7.50	4.95
6-8	20.00	7.50	4.92
6-9	20.00	7.50	4.90
6-10	20.00	7.40	4.85

(continued)

TABLE C-2 (continued)

Date	Water Temperature °C	pH	Staff Gauge Height, ft.
6-11	22.00	7.60	4.85
6-12	22.00	7.50	4.82
6-13	21.00	7.70	4.80
6-14	21.00	7.60	4.75
6-15	21.00	7.70	4.75
6-16	19.00	7.60	4.75
6-17	--	--	--
6-18	21.00	7.60	4.72
6-19	24.00	7.70	4.70
6-20	19.00	7.80	4.72
6-21	21.00	7.60	4.75
6-22	28.00	7.60	4.75
6-23	22.00	7.60	4.72
6-24	22.00	7.70	4.70
6-25	22.00	7.90	4.72
6-26	23.00	8.20	4.76
6-27	25.00	8.60	4.76
6-28	26.00	--	4.76
6-29	26.00	--	4.78
6-30	26.00	--	4.76
7-1	24.00	--	4.74
7-2	24.00	--	4.80
7-3	25.00	--	4.82
7-4	24.00	--	4.87
7-5	26.00	--	4.90
7-6	26.00	--	4.90
7-7	24.00	--	4.90
7-8	26.00	--	4.87
7-9	26.00	--	4.85
7-10	26.00	--	4.70
7-11	26.00	--	4.00
7-12	26.00	--	3.10
7-13	--	--	3.55
7-14	--	--	3.55
7-15	--	--	3.55

(continued)

TABLE C-2 (continued)

Date	Water Temperature °C	pH	Staff Gauge Height, ft.
7-16	--	--	3.55
7-17	--	--	3.53
7-18	--	--	3.50
7-19	--	--	3.45
7-20	--	--	3.45
7-21	--	--	3.45
7-22	--	--	3.45
7-23	--	--	3.55
7-24	--	--	3.55
7-25	--	--	3.50
7-26	--	--	3.50
7-27	24.00	7.70	3.55
7-28	23.00	7.90	3.55
7-29	23.00	8.00	3.55
7-30	20.00	7.80	3.52
7-31	21.00	7.90	3.50
8-1	--	--	3.50
8-2	21.00	7.90	3.10
8-3	--	--	2.60
8-4	--	--	1.65
8-5	--	--	1.65
8-6	--	--	1.65
8-7	--	--	1.64
8-8	--	--	1.64
8-9	21.00	7.80	1.63
8-10	--	--	1.85
8-11	--	--	1.90
8-12	--	--	1.87
8-13	--	--	1.80
8-14	--	--	1.82
8-15	--	--	1.84
8-16	26.00	7.20	1.90
8-17	--	--	1.90
8-18	--	--	1.87
8-19	--	--	1.85

(continued)

TABLE C-2 (continued)

Date	Water Temperature °C	pH	Staff Gauge Height, ft.
8-20	--	--	1.85
8-21	--	--	1.82
8-22	--	--	1.80
8-23	26.00	7.10	1.78
8-24	--	--	1.90
8-25	--	--	1.90
8-26	--	--	1.87
8-27	--	--	1.87
8-28	--	--	1.95
8-29	--	--	1.92
8-30	25.00	7.50	1.90
8-31	--	--	2.00
9-1	--	--	2.00
9-2	--	--	1.97
9-3	--	--	1.97
9-4	--	--	1.95
9-5	24.00	7.30	1.75
9-6	--	--	1.75
9-7	--	--	1.75
9-8	--	--	1.73
9-9	--	--	1.72
9-10	--	--	1.70
9-11	--	--	1.70
9-12	--	--	1.67
9-13	26.00	7.40	1.65
9-14	--	--	1.62
9-15	--	--	1.60
9-16	--	--	1.60
9-17	--	--	1.65
9-18	--	--	1.62
9-19	--	--	1.62
9-20	26.00	7.80	1.60
9-21	--	--	1.58
9-22	--	--	1.65
9-23	--	--	1.65

(continued)

TABLE C-2 (continued)

Date	Water Temperature °C	pH	Staff Gauge Height, ft.
9-24	--	--	1.62
9-25	--	--	1.60
9-26	--	--	1.60
9-27	14.00	8.10	1.57
9-28	--	--	1.57
9-29	--	--	1.60
9-30	--	--	1.65
10-1	--	--	1.65
10-2	--	--	1.65
10-3	--	--	1.70
10-4	18.00	8.00	1.70
10-5	--	--	1.70
10-6	--	--	1.70
10-7	--	--	1.67
10-8	--	--	1.67
10-9	--	--	1.65
10-10	--	--	1.65
10-11	--	--	1.67
10-12	--	--	1.67
10-13	--	--	1.67
10-14	--	--	1.65
10-15	--	--	1.65
10-16	--	--	1.62
10-17	--	--	1.60
10-18	14.00	8.20	1.65
10-19	--	--	1.60
10-20	--	--	1.60
10-21	--	--	1.60
10-22	--	--	1.57
10-23	--	--	1.57
10-24	--	--	1.57
10-25	14.00	8.10	1.60

TABLE C-3. RUNOFF RETENTION BASIN COD, NH_3-N, TKN, ORG-N, AND TOTAL-P CONCENTRATIONS IN SAMPLES COLLECTED AT THE FIELD SITE BETWEEN MAY AND NOVEMBER 1978

Date	COD mg/ℓ	NH_3-N mg/ℓ	TKN mg/ℓ	Org-N mg/ℓ	Total-P mg/ℓ
5-4	1,230	110	151	41	32
5-8	1,220	102	148	46	31
5-9	1,500	110	160	50	34
5-10	1,480	112	166	54	35
5-11	1,550	111	157	46	35
5-12	1,460	112	148	36	31
5-13	1,440	111	160	49	35
5-14	1,650	111	160	49	36
5-15	1,680	112	172	60	39
5-16	1,700	115	166	51	39
5-17	1,710	116	169	53	39
5-18	1,750	113	168	55	37
5-19	1,840	118	172	54	40
5-20	1,700	113	169	56	38
5-21	1,940	124	184	60	41
5-22	1,900	119	181	62	42
5-23	1,980	121	184	63	43
5-24	1,890	120	188	68	42
5-25	1,900	122	176	54	45
5-26	2,010	125	170	45	45
5-27	1,860	125	179	54	44
5-28	1,840	123	182	59	45
5-29	1,840	124	188	64	42
5-30	1,790	126	186	60	44
5-31	1,800	128	180	52	45
6-1	1,630	120	173	53	44
6-2	1,970	119	185	66	54
6-3	1,710	123	167	44	47
6-4	1,690	126	167	41	48
6-5	1,420	129	188	59	45
6-6	1,500	129	188	59	45
6-7	1,480	129	191	62	46
6-8	1,660	125	184	59	46
6-9	1,630	129	196	67	46
6-10	1,610	136	188	52	46

(continued)

TYPING GUIDE SHEET

TABLE C-3 (continued)

Date	COD mg/ℓ	NH_3-N mg/ℓ	TKN mg/ℓ	Org-N mg/ℓ	Total-P mg/ℓ
6-11	1,610	153	194	41	45
6-12	1,770	146	200	54	46
6-13	1,500	168	194	26	45
6-14	1,560	128	206	78	45
6-15	1,640	123	185	62	43
6-16	1,620	123	179	56	44
6-18	1,550	123	167	44	45
6-19	1,670	116	179	63	43
6-20	1,680	118	185	67	46
6-21	1,680	117	179	62	47
6-22	1,610	113	200	87	43
6-23	1,570	116	248	132	43
6-24	1,530	118	191	73	45
6-25	1,600	113	238	125	44
6-26	1,540	112	182	70	43
6-27	1,630	118	182	64	43
6-28	1,790	123	179	56	45
6-29	1,610	123	182	59	45
6-30	1,910	129	193	64	50
7-1	1,540	126	182	56	46
7-2	1,690	136	201	71	46
7-3	1,607	123	179	56	44
7-4	1,784	122	185	63	48
7-5	1,744	122	190	68	52
7-6	1,761	121	187	66	49
7-7	1,751	121	185	64	47
7-8	1,849	122	182	60	49
7-9	1,693	122	179	57	46
7-10	1,745	118	213	95	50
7-11	1,679	118	224	106	50
7-12	1,754	123	196	73	52
7-13	1,555	105	188	83	41
7-14	1,459	100	155	55	39
7-15	1,478	101	160	59	39
7-16	1,546	108	162	54	40

(continued)

EPA-287 (Cin.) (4-76)

TABLE C-3 (continued)

Date	COD mg/ℓ	NH_3-N mg/ℓ	TKN mg/ℓ	Org-N mg/ℓ	Total-P mg/ℓ
7-17	1,374	110	164	54	42
7-18	1,319	113	161	48	45
7-19	1,255	110	152	42	42
7-20	1,328	117	174	57	48
7-21	1,345	115	165	50	48
7-22	1,257	129	160	31	47
7-23	1,168	97	162	65	43
7-24	11,133	88	134	46	41
7-25	1,245	91	134	43	41
7-26	1,254	92	143	51	43
7-27	1,063	84	171	87	43
7-28	1,101	85	132	47	47
7-29	1,063	83	129	46	41
7-30	1,056	83	126	43	43
7-31	1,067	83	143	60	43
8-2	974	75	126	51	48
8-9	12,985	114	560	446	78
8-16	7,730	203	519	316	118
8-23	5,730	191	431	240	325
8-30	3,732	155	307	152	71
9-5	9,081	174	479	305	147
9-13	39,900	137	644	507	83
9-20	11,195	77	322	245	101
9-27	2,036	46	111	65	66
10-4	5,412	59	263	204	104
10-11	1,420	46	90	44	38
10-18	948	43	83	40	37
10-25	1,238	50	110	60	121

TABLE C-4. RUNOFF RETENTION BASIN SOLIDS CONCENTRATIONS IN SAMPLES COLLECTED AT THE FIELD SITE BETWEEN MAY AND NOVEMBER 1978

Date	TDS mg/ℓ	TSS mg/ℓ	FDS mg/ℓ	TVS mg/ℓ	VDS mg/ℓ	VSS mg/ℓ
5-4	1,647	157	897	900	750	150
5-8	1,535	255	920	805	615	190
5-9	1,685	375	960	995	725	270
5-10	1,680	365	985	960	695	265
5-11	1,655	350	880	1,070	775	295
5-12	1,670	365	935	1,045	735	310
5-13	1,685	420	925	1,090	760	330
5-14	1,730	405	950	1,105	780	325
5-15	1,830	390	1,000	1,140	830	310
5-16	1,850	350	970	1,170	880	290
5-17	1,890	290	950	1,200	940	260
5-18	1,670	380	1,090	860	580	280
5-19	1,710	360	1,100	910	610	300
5-20	1,670	340	1,040	920	630	290
5-21	1,860	410	1,110	1,080	750	330
5-22	2,040	390	1,010	1,420	1,030	390
5-23	2,060	371	1,089	1,321	971	350
5-24	2,000	360	990	1,340	1,010	330
5-25	1,940	330	1,230	1,010	710	300
5-26	1,900	330	1,260	910	640	270
5-27	1,850	280	1,120	1,000	730	270
5-28	1,880	330	1,160	990	720	270
5-29	2,120	380	1,110	1,320	1,010	310
5-30	2,160	390	1,210	1,280	950	330
5-31	2,200	300	1,190	1,280	1,010	270
6-1	2,120	410	1,220	1,200	900	300
6-2	2,600	2,280	1,800	1,320	800	520
6-3	2,290	390	1,230	1,300	1,060	240
6-4	1,730	320	1,020	920	710	210
6-5	1,960	360	1,270	1,000	690	310
6-6	2,110	290	1,250	1,130	860	270
6-7	2,000	290	1,210	1,070	790	280
6-8	2,020	380	1,380	950	640	310
6-9	2,010	300	1,340	920	670	250
6-10	2,030	330	1,370	930	660	270

(continued)

TABLE C-4 (continued)

Date	TDS mg/ℓ	TSS mg/ℓ	FDS mg/ℓ	TVS mg/ℓ	VDS mg/ℓ	VSS mg/ℓ
6-11	2,090	380	1,380	1,030	710	320
6-12	2,100	480	1,310	1,220	790	430
6-13	2,270	470	1,300	1,340	970	370
6-14	2,260	400	1,390	1,230	870	360
6-15	2,150	410	1,230	1,270	920	350
6-16	2,160	390	1,260	1,250	900	350
6-18	2,140	440	1,190	1,340	950	390
6-19	2,230	380	1,250	1,300	980	320
6-20	2,230	390	1,270	1,290	960	330
6-21	2,200	370	1,270	1,240	930	310
6-22	2,340	420	1,430	1,200	910	290
6-23	2,310	510	1,370	1,340	940	400
6-24	2,350	480	1,380	1,330	970	360
6-25	2,360	410	1,400	1,290	960	330
6-26	2,310	310	1,410	1,150	900	250
6-27	2,410	370	1,390	1,300	1,020	280
6-28	2,530	350	1,470	1,320	1,060	260
6-29	2,250	320	1,290	1,200	960	240
6-30	2,480	560	1,440	1,450	1,040	410
7-1	2,420	310	1,380	1,290	1,040	250
7-2	2,470	310	1,370	1,360	1,100	260
7-3	2,470	330	1,380	1,330	1,090	240
7-4	2,490	290	1,420	1,310	1,070	240
7-5	2,370	300	1,410	1,200	960	240
7-6	2,550	310	1,410	1,370	1,140	230
7-7	2,490	510	1,390	1,410	1,100	310
7-8	2,470	580	1,370	1,500	1,100	400
7-9	2,360	290	1,270	1,350	1,090	260
7-10	2,300	260	1,360	1,140	940	200
7-11	2,360	220	1,470	990	890	100
7-12	2,410	380	1,440	1,260	970	290
7-13	2,080	500	1,310	1,090	770	320
7-14	2,220	160	1,280	1,070	940	130
7-15	2,100	160	1,230	1,000	870	130
7-16	2,220	240	1,280	1,110	940	170

(continued)

TABLE C-4 (continued)

Date	TDS mg/ℓ	TSS mg/ℓ	FDS mg/ℓ	TVS mg/ℓ	VDS mg/ℓ	VSS mg/ℓ
7-17	2,010	240	1,240	980	770	210
7-18	2,840	330	2,110	950	730	220
7-19	2,340	140	1,670	770	670	100
7-20	2,090	180	1,210	1,010	880	130
7-21	2,010	310	1,160	1,080	850	230
7-22	2,080	270	1,200	1,060	880	180
7-23	2,060	210	1,210	1,000	850	150
7-24	1,980	200	1,140	1,010	840	170
7-25	1,940	190	1,130	950	810	140
7-26	1,990	170	1,240	890	750	140
7-27	1,735	240	1,090	815	645	170
7-28	1,950	190	1,205	895	745	150
7-29	1,985	185	1,220	915	765	150
7-30	2,000	165	1,285	845	715	130
7-31	1,900	395	1,195	950	705	245
8-2	2,250	670	1,320	1,290	930	360
8-9	2,850	6,150	1,800	3,800	1,050	2,750
8-16	2,733	10,733	1,800	7,600	933	6,667
8-23	3,300	22,600	3,100	13,700	200	13,500
8-30	20,760	4,480	13,800	9,800	6,960	2,840
9-5	2,889	12,000	2,111	8,445	778	7,667
9-13	4,917	9,150	3,883	5,851	1,034	4,817
9-20	3,280	6,880	1,920	5,760	1,360	4,400
9-27	3,180	2,660	2,060	2,280	1,120	1,160
10-4	4,100	9,950	2,400	7,200	1,700	5,500
10-11	3,055	730	2,030	1,460	1,025	435
10-18	2,918	408	2,013	1,153	905	248
10-25	2,800	15,733	1,867	9,866	933	8,933

TABLE C-5. RUNOFF RETENTION BASIN INDICATOR MICROORGANISM CONCENTRATIONS IN SAMPLES COLLECTED AT THE FIELD SITE BETWEEN MAY AND NOVEMBER 1978

Date	TC No./100 ml	FC No./100 ml	FS No./100 ml
5-4	8,700	3,300	2,650
5-17[a,b]	250,000	120,000	80,000
5-21[a]	300,000	100,000	80,000
5-28	100,000	55,000	80,000
5-31	100,000	63,000	120,000
6-7	16,000	4,400	7,000
6-11	16,000	2,800	6,400
6-14	30,000	2,000	13,000
6-18	23,000	2,400	9,000
6-21[a]	100,000	80,000	18,000
6-25	80,000	40,000	40,000
6-28[a,b]	200,000	100,000	60,000
7-2	500,000	140,000	50,000
7-12[b]	300,000	40,000	60,000
7-16[a]	200,000	100,000	80,000
7-19	100,000	60,000	22,000
7-23[a]	200,000	40,000	40,000
7-30	150,000	80,000	120,000
8-2	30,000	5,600	240,000
8-9	23,000	12,000	500,000
8-16[a,b]	2,000,000	25,000	800,000
8-23	600,000	46,000	400,000
8-30[a]	130,000	60,000	600,000
9-5	100,000	60,000	400,000
9-13	200,000	80,000	500,000
9-20	60,000	20,000	200,000
9-27	17,000	8,000	90,000
10-4	18,000	11,000	80,000
10-11	20,000	13,000	40,000
10-18	20,000	10,000	30,000
10-25	25,000	12,000	20,000

Notes: a. denotes rainfall in excess of 1.2 cm (0.5 in) since previous sampling

b. denotes waste was pumped into the retention basin since prior sampling

APPENDIX D

FIELD DATA FROM AMMONIA VOLATILIZATION EXPERIMENTS

TABLE D-1. TEMPERATURE AND CONSTITUENT CONCENTRATIONS MEASURED DURING NH_3-N VOLATILIZATION EXPERIMENTS

Date	Ambient Air Temp.	Parameter	Concentration at Source (mg/ℓ)	Concentration in Field Collectors (mg/ℓ)	Near Spray (mg/ℓ)	Far Spray (mg/ℓ)
7/16	74°F	NH_3-N	224.4	---	224.0	223.7
		TDS	1240	1124		
		VDS	500	568		
		TSS	1740	1416		
		VSS	1140	836		
		pH	7.1	7.0		
7/20	72°F	NH_3-N	215.0	---	214.7	210.9
		TKN	247	235		
		COD	1354	675		
		PO_4-P	77	59		
		TDS	780	764		
		VDS	180	220		
		TSS	1360	1344		
		VSS	900	752		
7/22	70°F	NH_3-N	240.3	---	240.1	255.7
		TKN	470	399		
		COD	951	857		
		PO_4-P	130	112		
		TDS	1080	948		
		VDS	400	400		
		TSS	508	568		
		VSS	336	392		
		pH	7.1	7.0		

At this point, the system was changed to the second form.

(continued)

TABLE D-1 (continued)

Date	Ambient Air Temp.	Parameter	Concentration at Source (mg/ℓ)	Concentration in Field Collectors (mg/ℓ)	Near Spray (mg/ℓ)	Far Spray (mg/ℓ)
7/31	62°F	NH_3-N	174.1	---	174.0	173.9
		TKN	177	179		
		COD	439	447		
		PO_4-P	39	50		
		TDS	542	568		
		VDS	132	128		
		TSS	46	71		
		VSS	40	50		
		pH	6.9	7.0		
8/1	72°F	NH_3-N	72.42	---	72.24	72.16
8/2	74°F	NH_3-N	87.66	---	87.36	87.59
		pH	7.0	7.0		
8/3	66°F	NH_3-N	104.37	---	104.16	104.37
		TKN	124	123		
		COD	515	462		
		PO_4-P	46	44		
		TDS	546	647		
		VDS	136	139		
		TSS	188	180		
		VSS	140	161		
8/7	94°F	NH_3-N	108.08	---	107.89	43.12
		TKN	114	117		
		COD	497	459		
		PO_4-P	46	49		
		TDS	606	681		
		VDS	168	169		
		TSS	116	51		
		VSS	92	43		
8/8	76°F	NH_3-N	114.10	---	114.05	113.94
		pH	7.1	7.0		
8/9	94°F	NH_3-N	177.2	---	176.8	175.5
		TKN	208	199		
		COD	431	470		
		PO_4-P	47	58		
		TDS	693	639		
		VDS	205	205		

(continued)

TABLE D-1 (continued)

Date	Ambient Air Temp.	Parameter	Concentration at Source (mg/ℓ)	Concentration in Field Collectors (mg/ℓ)	Near Spray (mg/ℓ)	Far Spray (mg/ℓ)
		TSS	115	115		
		VSS	74	74		
8/10	88°F	NH_3-N	69.03	---	68.99	68.84
8/11	68°F	NH_3-N	59.56			
		TKN	67	69		
		COD	425	463		
		PO_4-P	26	22		
		TDS	337	361		
		VDS	97	84		
		TSS	175	142		
		VSS	138	120		
		pH	6.9	7.0		
8/14	78°F	NH_3-N	68.70	---	68.77	68.43
		TKN	79	81		
		COD	294	294		
		PO_4-P	30	25		
		TDS	492	481		
		VDS	156	140		
		TSS	98	87		
		VSS	88	85		
8/15	80°F	NH_3-N	60.43	---	60.48	62.55
		TKN	75	78		
		COD	465	436		
		PO_4-P	49	43		
		TDS	376	358		
		VDS	106	104		
		TSS	94	94		
		VSS	84	79		
8/16	70°F	NH_3-N	79.26	---	78.96	79.08
		pH	7.0	6.9		
8/17	78°F	NH_3-N	99.27	---	99.31	99.26
8/21	58°F	NH_3-N	67.68	---	67.57	67.74
8/23	50°F	NH_3-N	71.05	---	71.12	70.91

(continued)

TABLE D-1 (continued)

Date	Ambient Air Temp.	Parameter	Concentration at Source (mg/ℓ)	Concentration in Field Collectors (mg/ℓ)	Near Spray (mg/ℓ)	Far Spray (mg/ℓ)
8/24	56°F	NH_3-N	68.70	---	68.77	68.43
		TKN	94	93		
		COD	380	376		
		PO_4-P	33	33		
		TDS	500	478		
		VDS	168	129		
		TSS	68	67		
		VSS	60	63		
		pH	7.0	7.0		
8/29	74°F	NH_3-N	85.02	---	84.90	84.11
		TKN	105	100		
		COD	679	654		
		PO_4-P	33	41		
		TDS	528	529		
		VDS	136	133		
		TSS	220	138		
		VSS	170	137		
8/30	76°F	NH_3-N	95.11	---	94.86	92.06
		TKN	105	108		
		COD	673	678		
		PO_4-P	34	35		
		TDS	488	488		
		VDS	168	172		
		TSS	196	184		
		VSS	184	174		
9/4	72°F	NH_3-N	101.84	---	101.92	101.72
		pH	7.0	7.0		
9/5	76°F	NH_3-N	93.65	---	93.41	92.00
9/6	74°F	NH_3-N	80.24	---	80.19	91.17
		TKN	89	94		
		COD	307	313		
		PO_4-P	46	41		
		TDS	676	651		
		VDS	206	209		
		TSS	64	60		
		VSS	62	60		

(continued)

TABLE D-1 (continued)

Date	Ambient Air Temp.	Parameter	Concentration at Source (mg/ℓ)	Concentration in Field Collectors (mg/ℓ)	Near Spray (mg/ℓ)	Far Spray (mg/ℓ)
9/7	78°F	NH_3-N	194	---	192.1	193.8
		TKN	227	221		
		COD	507	526		
		PO_4-P	50	61		
		TDS	721	695		
		VDS	176	162		
		TSS	73	70		
		VSS	49	46		
		pH	7.1	7.0		
9/12	72°F	NH_3-N	107.42	---	107.18	109.13
9/14	82°F	NH_3-N	68.42	---	68.32	56.56
		TKN	96	86		
		COD	452	482		
		PO_4-P	27	34		
		TDS	333	426		
		VDS	91	98		
		TSS	87	86		
		VSS	68	78		

APPENDIX E

LABORATORY QUALITY CONTROL

TABLE E-1. SUMMARY OF QUALITY CONTROL ANALYSES FOR FEEDLOT RUN-OFF WASTEWATER LABORATORY MAY 8 TO JULY 6, 1978

Parameter	Standard	Results, mg/ℓ	Date	
TKN	240 mg/ℓ alanine	239	5/11	
		237	5/11	$\overline{x}$ = 241.43
		231	5/11	σ = 6.901
		240	5/11	Recovery = 96.6%
		244	5/24	% S.D./$\overline{x}$ = 2.86%
		252	6/2	
		247	6/8	
TKN	200 mg/ℓ proline	191	6/8	Recovery = 95.5%
TKN	500 mg/ℓ NH_4Cl	479	5/9	$\overline{x}$ = 475.67
		470	5/11	σ = 4.933 Recovery - 95.13%
		478	5/11	% S.D./$\overline{x}$ = 1.04%
NH_3-N	100 mg/ℓ NH_4Cl	104	5/31	Recovery = 104%
COD	500 mg/ℓ potassium acid phthalate (KHP)	492	5/9	$\overline{x}$ = 494.0
		496	6/8	σ = 2.828 Recovery = 98.8% % S.D./$\overline{x}$ = 0.57%

(continued)

TABLE E-1 (continued)

Parameter	Standard	Results, mg/ℓ	Date	
Total-P	(Replicates)	37	5/15	
		37	5/15	
		37	5/15	
		37	5/15	
		37	5/15	$\overline{x}$ = 37.25
		38	5/15	σ = 0.452
		37	5/15	% σ/$\overline{x}$ = 1.21%
		38	5/15	
		37	5/15	
		38	5/15	
		37	5/15	
		37	5/15	

APPENDIX F

DEFINITIONS OF TERMS AND COMPUTER PROGRAM FOR CATTLE FEEDLOT RUNOFF RETENTION BASIN QUALITY PREDICTIONS

```
* A ... CONSTANT FACTOR FOR CALCULATING LCODD.
* A2 ... CONSTANT FACTOR FOR CALCULATING LORGNA.
* AVEVAP ... AVERAGE ANNUAL LAKE EVAPORATION
* AVPRCP ... AVERAGE ANNUAL PRECIPITATION
* B ... CONSTANT FACTOR FOR CALCULATING LCODN.
* B2 ... CONSTANT FACTOR FOR CALCULATING LORGNN.
* C ... CONSTANT FACTOR FOR CALCULATING SCODL.
* C2 ... CONSTANT FACTOR FOR CALCULATING SORGNL.
* CCOD ... CONCENTRATION OF COD IN RUNOFF (MG/L)
* D ... CONSTANT FACTOR FOR CALCULATING SCODN.
* D2 ... CONSTANT FACTOR FOR CALCULATING SORGNN.
* DCHGPT ... PHOSPHORUS REMOVED BY DISCHARGE (KG/HA)
* DISPT ... PHOSPHORUS REMOVED BY DISPOSAL (KG/HA)
* DISVOL ... DAILY DISPOSAL VOLUME (CU M/HA)
* DSCHRG ... DAILY DISCHARGE (OVERFLOW) VOLUME (CU M/HA)
* E ... CONSTANT FACTOR FOR CALCULATING SLUDGE.
* FCOLI ... POND CONCENTRATION OF FECAL C CLIFORM (PER 100 ML)
* FDS ... FIXED DISSOLVED SOLIDS CONCENTRATION (MG/L) IN RUNOFF.
* FNH3 ... AMMONIA FRACTION OF TOTAL NITRCGEN PRESENT IN RUNOFF.
* FRZC ... CURRENT DAY*S GROUND CONDITION
* FRZ1 ... PREVIOUS DAY*S GROUND CONDITION ...
* FSTRP ... POND CONCENTRATION OF FECAL STREPTOCOCCUS (PER 100 ML)
* KAPT ... AMMONIFICATION RATE FACTOR (1/DAY)
* KCPT ... RATE CONSTANT FOR COD DEGRADATION (1/DAY)
* KC20 ... CONSTANT FACTOR FOR KCPT CALCULATION.
```

APPENDIX F (continued)

```
* KFS20 ... RATE CONSTANT FOR DEGRADATION OF FECAL STREPTOCOCCUS
* KFTC ... RATE CONSTANT FOR DEGRADATION OF COLIFORM BACTERIA
* KFTC20 ... CONSTANT FACTOR FOR KFTC CALCULATION.
* KI ... RAINFALL INTENSITY FACTOR.
* KL ... LOT SURFACE MATERIAL FACTOR.
* KLPT ... RATE CONSTANT FOR LIQUEFACTION OF SOLIDS (1/DAY)
* KL20 ... CONSTANT FACTOR FOR KLPT CALCULATION.
* KM ... LOT MOISTURE FACTOR.
* KP ... SOURCE OF RUNOFF FACTOR (RAINFALL OR SNOWMELT)
* KSA ... SALT ACCUMULATION FACTOR.
* KT ... TEMPERATURE FACTOR.
* KTB ... TEMPERATURE CORRECTION FACTOR FOR BACTERIA IN RUNOFF.
* LCODD ... LIQUID COD DEGRADABLE (KG/HA)
* LCODN ... LIQUID COD NON-DEGRADABLE (KG/HA)
* LCODT ... AMOUNT OF COD IN LIQUID (KG/HA)
* LFDS ... TOTAL FIXED DISSOLVED SOLIDS IN POND LIQUID (KG/HA)
* LFDSD ... TOTAL FIXED DISSOLVED SOLIDS REMOVED BY DISCHARGE (KG/HA)
* LFDST ... TOTAL FIXED DISSOLVED SOLIDS REMOVED BY DISPOSAL (KG/HA)
* LM ... LOT MOISTURE AT THE START OF ANY DAY (MM)
* LMHC ... LOT MOISTURE HOLDING CAPACITY (MM)
* LNH3 ... LIQUID AMMONIA NITROGEN (KG/HA)
* LORGNA ... AMMONIFIABLE ORGANIC NITROGEN IN LIQUID (KG/HA)
* LORGNN ... NON-AMMONIFIABLE ORGANIC NITROGEN IN LIQUID (KG/HA)
* LORGNT ... TOTAL LIQUID ORGANIC NITROGEN (KG/HA)
* LTAREA ... AREA OF FEEDLOT (ACRES)
* LTVS ... TOTAL VOLATILE SOLIDS IN POND LIQUID (KG/HA)
* NH3 ... TOTAL AMMONIA CONCENTRATION (MG/L) IN RUNOFF.
* NTOT ... TOTAL NITROGEN CONCENTRATION (MG/L) IN RUNOFF.
* PCOD ... CONCENTRATION OF COD IN POND LIQUID (MG/L)
* PF ... PROPORTIONING FACTOR FOR DRY LOT MOISTURE EVAPORATION CONDITIONS.
* PFDS ... POND LIQUID CONCENTRATION OF FIXED DISSOLVED SOLIDS (MG/L)
* PL ... PARTIAL PRESSURE OF AMMONIA IN LIQUID (1.E-6 ATM)
* PLSA ... POND LIQUID SURFACE AREA FOR DAY (SQ FT)
* PNH3 ... POND LIQUID AMMONIA NITROGEN CONCENTRATION (MG/L)
* PONVOL ... DAILY POND VOLUME (CU M/HA)
* PORGN ... POND LIQUID CONCENTRATION OF ORGANIC NITROGEN (MG/L)
```

APPENDIX F (continued)

```
* PRECIP ... DAILY PRECIPITATION (MM)
* PRECP ... TOTAL NEWLY-PRECIPITATED PHOSPHORUS IN SLUDGE (KG/HA)
* PRECPT ... CUMULATIVE TOTAL OF SLUDGE PHOSPHORUS (KG/HA)
* PT ... TEMPERATURE OF LIQUID IN POND (DEG.C)
* PTOTN ... POND LIQUID CONCENTRATION OF TOTAL NITROGEN (MG/L)
* PTOTP ... PHOSPHORUS CONCENTRATION IN POND LIQUID (MG/L)
* PTOTPM ... MAXIMUM PHOSPHORUS SOLUBILITY IN LIQUID (MG/L)
* PTS ... POND LIQUID CONCENTRATION OF TOTAL SOLIDS (MG/L)
* PTVS ... POND LIQUID CONCENTRATION OF TOTAL VOLATILE SOLIDS (MG/L)
* RCOD ... RUNOFF COD (KG/HA)
* RFCOLI ... FECAL COLIFORM CONCENTRATION (PER 100 ML OF RUNOFF)
* RFDS ... TOTAL FIXED DISSOLVED SOLIDS IN RUNOFF (KG/HA)
* RFSTRP ... FECAL STREPTOCOCCUS CONCENTRATION (PER 100 ML OF RUNOFF)
* RNH3 ... RUNOFF AMMONIA NITROGEN FOR DAY (KG/HA)
* RORGN ... ORGANIC RUNOFF NITROGEN (KG/HA)
* RTCOLI ... TOTAL COLIFORM CONCENTRATION (PER 100 ML OF RUNOFF)
* RTOTN ... TOTAL RUNOFF NITROGEN FOR DAY (KG/HA)
* RTCTP ... TOTAL RUNOFF PHOSPHORUS (KG/HA)
* RUNCFF ... DAILY RUNOFF VOLUME (CU M/HA)
* SCODL ... SOLID COD LIQUEFIABLE (KG/HA)
* SCODN ... SOLID COD NON-LIQUEFIABLE (KG/HA)
* SLUCGE ... SLUDGE MASS (KG/HA)
* SORGNL ... LIQUEFIABLE ORGANIC NITROGEN IN SOLIDS (KG/HA)
* SORGNN ... NON-AMMONIFIABLE ORGANIC NITROGEN IN SOLID (KG/HA)
* T ... TIME SINCE CURRENT RUNOFF BEGAN (DAYS)
* TCOLI ... TOTAL POND CONCENTRATION OF C CLIFORM BACTERIA (PER 100 ML)
* TOTP ... TOTAL PHOSPHORUS IN POND LIQUID (KG/HA)
* TS ... LOT SURFACE TEMP (DEG.C)
* TVS ... TOTAL VOLATILE SOLIDS CONCENTRATION (MG/L)
* T0 ... CURRENT AVERAGE DAILY TEMP (DEG.C)
* T1-T9 ... AVERAGE TEMPS (C) FROM 1-9 DAY*S PRIOR TO CURRENT DAY.
* VNH3 ... AMMONIA NITROGEN VOLATIZED FROM LIQUID SURFACE (KG/HA)
* WINDD ... AVERAGE MONTHLY WINDRUN AT FEEDLOT (MILES/DAY)
```

Reproduced from
best available copy.

```
*RQM
      PROGRAM RQM
     +    (INPUT=/130,OUTPUT=/130,TAPE2,TAPE3,TAPE4,TAPE5,TAPE1=INPUT)
*
* TAPE 1 ... INITIALIZATION INPUT
* TAPE 2 ... DAILY INPUT FILE (FILE MARKS INDICATE MANUAL ADJUSTMENTS)
* TAPE 3,4 ... DAILY PLOT OUTPUT FILES (FILE MARKS INDIC.MAN.ADJUST.)
*
* PONVOL ... DAILY POND VOLUME (CU M/HA)
* PRECIP ... DAILY PRECIPITATION (MM)
* RUNOFF ... DAILY RUNOFF VOLUME (CU M/HA)
* DISVOL ... DAILY DISPOSAL VOLUME (CU M/HA)
* DSCHRG ... DAILY DISCHARGE (OVERFLOW) VOLUME (CU M/HA)
* T0 ... CURRENT AVERAGE DAILY TEMP (DEG.C)
* FRZ0 ... CURRENT DAY*S GROUND CONDITION ...
*                   1 = GROUND FROZEN.
*                   0 = GROUND THAWED.
*
*    (T1, T2, ... T9 ARE ANTECEDENT TEMPS FOR 1, 2, ... 9 DAYS
*      PRIOR TO CURRENT DAY; FRZ1 IS PREVIOUS DAY*S GROUND CONDITION.)
*
* WINDD ... AVERAGE MONTHLY WINDRUN AT FEEDLOT (MILES/DAY)
* LTAREA ... AREA OF FEEDLOT (ACRES)
* PLSA ... POND LIQUID SURFACE AREA FOR DAY (SQ FT)
*
*
      IMPLICIT REAL (A-Z)
      INTEGER T,MO,DA,YR,FRZ0,FRZ1,INDFRZ,IR,JDATE
      LOGICAL START
*
*
      EQUIVALENCE (A,A2),(B,B2),(C,C2),(D,D2)
      DATA LM,RUNOFF,PRECIP,LCODD,LCODN,SCODN,SCODL,
     +    SORGNL,SORGNN,LORGNA,LORGNN,LNH3,TOTP,PRECPT,DCHGPT,DISPT,
     +    LFDS,LFDST,LFDSD,TCOLI,FCOLI,FSTRP/22*0.0/,
     +    T,FRZ1/2*0/,START/.TRUE./
      NAMELIST/LPP/KL,LMHC,KL20,KC20,A,B,C,D,E,AVEVAP,AVPRCP,
     +    KFS20,KFTC20,LNH3,TOTP,LCODC,LCODN,TCOLI,FCCLI,FSTRP,LFDS,
     +    LFDST,LFDSD,LCRGNA,LORGNN,SORGNL,SORGNN,SCODL,SCODN
      NAMELIST/BETA/JDATE,MO,DA,YR,PONVOL,PRECIP,RUNOFF,DISVOL,DSCHRG,
     +    WINDD,PLSA,LTAREA,LMHC,LM,PF,KI,KT,KM,KL,KP,KT9,KSA,K,K2,
     +    AVEVAP,AVPRCP,T0,FRZ0,TS,PT,LCODD,LCODN,SCODL,SCODN,CCOD,RCOD,
     +    LCODT,PCOD,SLUDGE,A,A2,B,B2,C,C2,D,D2,E,KCPT,KLPT,KL20,KC20,
     +    T,NTOT,NH3,FNH3,RTOTN,RORGN,LORGNA,KAPT,SORGNL,LORGNN,SORGNN,
     +    LORGNT,PORGN,RNH3,LNH3,VNH3,PL,PNH3,PTOTN,RTCOLI,RFCOLI,RFSTRP,
     +    FDS,P,TVS,RTOTP,TOTP,PRECP,PRECPT,PTOTP,PTOTPM,DISPT,DCHGPT,
     +    RFDS,LFDS,PFDS,LTVS,PTVS,PTS,LFDST,LFDSD,TCOLI,FCOLI,FSTRP
*
CONVERSION & ROUNDOFF FUNCTIONS:
* ACRE-INCH/ACRE TO CU.M/HECTARE ...
      CMH(AIA)=AIA*254.
* CU.M/HA TO A-IN/A ...
      AIA(CMH)=CMH/254.
* INCHES TO MILLIMETERS ...
      MM(IN)=IN*25.4
* MILLIMETERS TO INCHES ...
      IN(MM)=MM/25.4
* KG/HA TO LBS/ACRE ...
      PA(KH)=KH/1.1206593
* DEGREES FAHRENHEIT TO CELSIUS ...
      DC(F)=5./9.*(F-32.)
* DEG.CELSIUS TO FAHR. ...
      DF(C)=C*9./5.+32.
*
* INPUT INITIAL LOT AND POND PARAMETERS.
    5 READ(1,LPP)
      IF(EOF(1).NE.0)CONTINUE
* START LM = LMHC FOR INITIAL TEST ...
         IF(START)LM=LMHC
* INPUT FIRST DAY*S VARIABLES (ENGLISH UNITS)
      READ(2,200)JDATE,YR,MO,DA,PONVOL,RUNOFF,PRECIP,DISVOL,
     +    DSCHRG,WINDD,PLSA,T0,FRZ0,LTAREA,GGHT
      IF(EOF(2).NE.0)STOP
      IF(.NOT.START)GO TO 15
      PRINT 502  $  PRINT 503  $  PRINT 500
      WRITE(3,502)  $  WRITE(3,503)  $  WRITE(3,300)  $  ENDFILE 3
      WRITE(4,502)  $  WRITE(4,503)  $  WRITE(4,400)  $  ENDFILE 4
      WRITE(5,502)  $  WRITE(5,503)
* INITIALIZE ANTECEDENT TEMPERATURE VARIABLES.
      T0=DC(T0)
      T9=T8=T7=T6=T5=T4=T3=T2=T1=T0
      START=.FALSE.
      GOTO 20
*
```

APPENDIX F (continued)

```
*
*
* INPUT DAILY VARIABLES (ENGLISH UNITS) ... BEGIN DAILY LOOP
  10   READ(2,200)JDATE,YR,MO,DA,PONVOL,RUNOFF,PRECIP,DISVOL,
     +     DSCHRG,WINDD,PLSA,T0,FRZ0,LTAREA,GGHT
       IF(EOF(2).EQ.0)GOTO 15
       ENDFILE 3  $  ENDFILE 4
CHECK FOR ADJUSTMENT PARAMETERS FOR MANUAL INTERVENTION IN POND OPERATION.
       GOTO 5
CONVERT VARIABLES TO METRIC EQUIVALENTS AS SPECIFIED ABOVE
  15   T0=OC(T0)
  20   PONVOL=CMH(PONVOL)
       PRECIP=MM(PRECIP)
       RUNOFF=CMH(RUNOFF)
       DSCHRG=CMH(DSCHRG)
       DISVOL=CMH(DISVOL)
*
* LMHC ... LOT MOISTURE HOLDING CAPACITY (MM)
* LM ... LOT MOISTURE AT THE START OF ANY DAY (MM)
* PF ... PROPORTIONING FACTOR FOR DRY LOT MOISTURE EVAPORATION CONDITIONS.
       PF=1.0
*
* KI ... RAINFALL INTENSITY FACTOR.
* KT ... TEMPERATURE FACTOR.
* KM ... LOT MOISTURE FACTOR.
* KL ... LOT SURFACE MATERIAL FACTOR.
* KP ... SOURCE OF RUNOFF FACTOR (RAINFALL OR SNOWMELT)
* TS ... LOT SURFACE TEMP (DEG.C)
* PT ... TEMPERATURE OF LIQUID IN POND (DEG.C)
       TS=(5.*T0+4.*T1+3.*T2+2.*T3+T4)/15.
       PT=(T0+T1+T2+T3+T4+T5+T6+T7+T8+T9)/10.
       KI=1.0
       IF(PRECIP.GT.0.0)KI=(PRECIP/254.)**(-0.4)
       KT=10.**(0.018*TS-0.38)
       KM=0.5*(1.0+LM/LMHC)
*
* ASSUME RUNOFF IS FROM MELTING SNOW IF GROUND CONDITION
*   WAS FROZEN YESTERDAY AND IS THAWED TODAY.
       KP=1.0
       IF(FRZ0.EQ.0.AND.FRZ1.EQ.1)KP=5.0
       IF(RUNOFF.EQ.0.)KP=0.0
*
* LCODD ... LIQUID COD DEGRADABLE (KG/HA)
* LCODN ... LIQUID COD NON-DEGRADABLE (KG/HA)
* SCODL ... SOLID COD LIQUEFIABLE (KG/HA)
* SCODN ... SOLID COD NON-LIQUEFIABLE (KG/HA)
* CCOD ... CONCENTRATION OF COD IN RUNOFF (MG/L)
* RCOD ... RUNOFF COD (KG/HA)
* LCODT ... AMOUNT OF COD IN LIQUID (KG/HA)
* PCOD ... CONCENTRATION OF COD IN POND LIQUID (MG/L)
* SLUDGE ... SLUDGE MASS (KG/HA)
*
* KTB ... TEMPERATURE CORRECTION FACTOR FOR BACTERIA IN RUNOFF.
* KSA ... SALT ACCUMULATION FACTOR.
* AVEVAP ... AVERAGE ANNUAL LAKE EVAPORATION
* AVPRCP ... AVERAGE ANNUAL PRECIPITATION
* RTCOLI ... TOTAL COLIFORM CONCENTRATION (PER 100 ML OF RUNOFF)
* RFCOLI ... FECAL COLIFORM CONCENTRATION (PER 100 ML OF RUNOFF)
* RFSTRP ... FECAL STREPTOCOCCUS CONCENTRATION (PER 100 ML OF RUNOFF)
* FDS ... FIXED DISSOLVED SOLIDS CONCENTRATION (MG/L) IN RUNOFF.
* P ... TOTAL PHOSPHORUS CONCENTRATION (MG/L) IN RUNOFF.
* TVS ... TOTAL VOLATILE SOLIDS CONCENTRATION (MG/L)
*
* A, B, C, D, E ARE CONSTANT FACTORS FOR CALCULATING LCODD, LCODN, SCODL,
*   SCODN, AND SLUDGE, RESPECTIVELY.
* KCPT ... RATE CONSTANT FOR COD DEGRADATION (1/DAY)
* KLPT ... RATE CONSTANT FOR LIQUEFACTION OF SOLIDS (1/DAY)
* KL20, KC20 ... CONSTANT FACTORS.
* T ... TIME SINCE CURRENT RUNOFF BEGAN (DAYS)
* NTOT ... TOTAL NITROGEN CONCENTRATION (MG/L) IN RUNOFF.
* NH3 ... TOTAL AMMONIA CONCENTRATION (MG/L) IN RUNOFF.
* FNH3 ... AMMONIA FRACTION OF TOTAL NITROGEN PRESENT IN RUNOFF.
       T=T+1
       IF(RUNOFF.EQ.0.)T=0
       KLPT=KL20*1.45**(PT-20)
       KCPT=KC20*1.072**(PT-20)
       KTB=10.**(0.8-0.04*TS)
       KSA=1.0+AVEVAP/AVPRCP
       K=KI*KM*KL*KP
       K2=K*KTB
       K=K*KT
       CCOD=4200.*K
       NTOT=800.*K
       FNH3=0.4*(KT*LM/LMHC)**2
       NH3=FNH3*NTOT
```

APPENDIX F (continued)

Reproduced from best available copy.

```
      RCOD=RUNOFF*CCOD/1000.
      SCODL=SCODL*10.**(-KLPT)+RCOD*C
      SCODN=SCODN+RCOD*D
      RTCOLI=8.E6*K2
      RFCOLI=8.E6*K2
      RFSTRP=7.E6*K2
      FDS=5000.*K*KSA
      P=75.*K
      TVS=4600.*K
*
      IF(PONVOL.GT.0.0)GOTO 30
      LCODD=LCODN=LCODT=PCOD=0.0
      GOTO 40
*
   30 LCODD=LCODD*(10.**(-KCPT)-DISVOL/(DISVOL+PONVOL))
     +     +RCOD*A-((RCOD*A)+LCODD)*DSCHRG/(DSCHRG+PONVOL)
     +     +SCODL*(1.-10.**(-KLPT))
      LCODN=LCODN+RCOD*B-(LCODN*DISVOL/(DISVOL+PONVOL)
     +     +LCODN*DSCHRG/(DSCHRG+PONVOL))
      LCODT=LCODD+LCODN
      PCOD=LCODT*1000./PONVOL
   40 SLUDGE=SCODN*E
*
* RTOTN ... TOTAL RUNOFF NITROGEN FOR DAY (KG/HA)
* RORGN ... ORGANIC RUNOFF NITROGEN (KG/HA)
* LORGNA ... AMMONIFIABLE ORGANIC NITROGEN IN LIQUID (KG/HA)
* KAPT ... AMMONIFICATION RATE FACTOR (1/DAY)
* SORGNL ... LIQUEFIABLE ORGANIC NITROGEN IN SOLIDS (KG/HA)
* LORGNN ... NON-AMMONIFIABLE ORGANIC NITROGEN IN LIQUID (KG/HA)
* SORGNN ... NON-AMMONIFIABLE ORGANIC NITROGEN IN SOLID (KG/HA)
* LORGNT ... TOTAL LIQUID ORGANIC NITROGEN (KG/HA)
* PORGN ... POND LIQUID CONCENTRATION OF ORGANIC NITROGEN (MG/L)
* RNH3 ... RUNOFF AMMONIA NITROGEN FOR DAY (KG/HA)
* LNH3 ... LIQUID AMMONIA NITROGEN (KG/HA)
* VNH3 ... AMMONIA NITROGEN VOLATIZED FROM LIQUID SURFACE (KG/HA)
* PL ... PARTIAL PRESSURE OF AMMONIA IN LIQUID (1.E-6 ATM)
* LTAREA ... FEEDLOT SURFACE AREA (ACRES)
* PNH3 ... POND LIQUID AMMONIA NITROGEN CONCENTRATION (MG/L)
* PTOTN ... POND LIQUID CONCENTRATION OF TOTAL NITROGEN (MG/L)
* A2, B2, C2, D2 ARE CONSTANT FACTORS FOR CALCULATING LORGNA, LORGNN,
*   SORGNL, AND SORGNN, RESPECTIVELY.
*
* ORGANIC-N
      RTOTN=RUNOFF*NTOT/1000.
      RORGN=RTOTN*(1.0-FNH3)
      LORGNT=PORGN=RNH3=VNH3=PNH3=PTOTN=0.0
      IF(RTOTN.GT.0.0)RORGN=RTOTN*(1.0-FNH3)
      KAPT=0.76*10.**(7.71-2758./(273.+PT))
      SORGNL=SORGNL*10.**(-KLPT)+RORGN*C2
      SORGNN=SORGNN+RORGN*D2
*
      IF(PONVOL.GT.0.0)GOTO 45
      LORGNA=LORGNN=LNH3=PL=
     +     TOTP=PRECP=PTOTP=PTOTPM=LFDS=PFDS=LTVS=PTVS=
     +     PTS=TCOLI=FCOLI=FSTRP=0.0
      GOTO 60
   45 LORGNA=LORGNA*10.**(-KAPT)+RORGN*A2
     +     -LORGNA*(DISVOL/(DISVOL+PONVOL))
     +     -(RORGN*A2+LORGNA)*(DSCHRG/(DSCHRG+PONVOL))
     +     +SORGNL*(1.0-10.**(-KLPT))
      IF(LORGNA.LT.0.0)LORGNA=0.0
      LORGNN=LORGNN+RORGN*B2-LORGNN
     +     *(DISVOL/(DISVOL+PONVOL))
     +     -(RORGN*B2+LORGNN)*(DSCHRG/(DSCHRG+PONVOL))
      IF(LORGNN.LT.0.0)LORGNN=0.0
      LORGNT=LORGNA+LORGNN
      PORGN=LORGNT*1000./PONVOL
*
* AMMONIA-N
      RNH3=RTOTN*FNH3
      PL=10.**(0.058*PT-3.04)*LNH3*1000./PONVOL
      VNH3=1.25E-2*WINDD**0.8*(TC+273.)**(-1.4)*PLSA/LTAREA*(PL-1.0)
      IF(VNH3.LT.0.0)VNH3=0.0
      LNH3=LNH3-VNH3+RNH3
     +     -LNH3*(DISVOL/(DISVOL+PONVOL))
     +     -LNH3*(DSCHRG/(DSCHRG+PONVOL))
     +     +LORGNA*(1.0-10.**(-KAPT))
      IF(LNH3.LT.0.0)LNH3=0.0
      PNH3=LNH3*1000./PONVOL
      PTOTN=PORGN+PNH3
```

APPENDIX F (continued)

```
*
* RTOTP ... TOTAL RUNOFF PHOSPHORUS (KG/HA)
* TOTP ... TOTAL PHOSPHORUS IN POND LIQUID (KG/HA)
* PRECP ... TOTAL NEWLY-PRECIPITATED PHOSPHORUS IN SLUDGE (KG/HA)
* PRECPT ... CUMULATIVE TOTAL OF SLUDGE PHOSPHORUS (KG/HA)
* PTOTP ... PHOSPHORUS CONCENTRATION IN POND LIQUID (MG/L)
* PTOTPM ... MAXIMUM PHOSPHORUS SOLUBILITY IN LIQUID (MG/L)
* DISPT ... PHOSPHORUS REMOVED BY DISPOSAL (KG/HA)
* DCHGPT ... PHOSPHORUS REMOVED BY DISCHARGE (KG/HA)
       RTOTP=P*RUNOFF/1000.
       PTOTPM=0.33*PNH3+24.4
       IF(PTOTPM.GT.120.)PTOTPM=120.
       TOTP=TOTP+RTOTP-TOTP*DISVOL/(PONVOL+DISVOL)
      +    -TOTP*DSCHRG/(DSCHRG+PONVOL)
       IF(TOTP.LT.0.0)TOTP=0.0
       PTOTP=TOTP*1000./PONVOL
       PRECP=0.0
       IF(PTOTP.LE.PTOTPM)GOTO 50
       PRECP=(PTOTP-PTOTPM)*PONVOL/1000.
       PTOTP=PTOTPM
       PRECPT=PRECPT+PRECP
       TOTP=TOTP-PRECP
  50   DCHGPT=DCHGPT+(TOTP*DSCHRG)/(DSCHRG+PONVOL)
       DISPT=DISPT+(TOTP*DISVOL)/(DISVOL+PONVOL)
* RFDS ... TOTAL FIXED DISSOLVED SOLIDS IN RUNOFF (KG/HA)
* LFDS ... TOTAL FIXED DISSOLVED SOLIDS IN POND LIQUID (KG/HA)
* PFDS ... POND LIQUID CONCENTRATION OF FIXED DISSOLVED SOLIDS (MG/L)
* LTVS ... TOTAL VOLATILE SOLIDS IN POND LIQUID (KG/HA)
* PTVS ... POND LIQUID CONCENTRATION OF TOTAL VOLATILE SOLIDS (MG/L)
* PTS ... POND LIQUID CONCENTRATION OF TOTAL SOLIDS (MG/L)
* LFDST ... TOTAL FIXED DISSOLVED SOLIDS REMOVED BY DISPOSAL (KG/HA)
* LFDSD ... TOTAL FIXED DISSOLVED SOLIDS REMOVED BY DISCHARGE (KG/HA)
       RFDS=FDS*RUNOFF/1000.
       LFDS=LFDS+RFDS-PRECP*7.0-LFDS*DISVOL/(DISVOL+PONVOL)
      +    -LFDS*DSCHRG/(DSCHRG+PONVOL)
       PFDS=LFDS*1000./PONVOL
       LTVS=LCODT*1.1
       PTVS=LTVS*1000./PONVOL
       PTS=PFDS+PTVS
       LFDST=LFDST+LFDS*DISVOL/(DISVOL+PONVOL)
       LFDSD=LFDSD+LFDS*DSCHRG/(DSCHRG+FONVOL)
*
* TCOLI ... TOTAL POND CONCENTRATION OF COLIFORM BACTERIA (PER 100 ML)
* FCOLI ... POND CONCENTRATION OF FECAL COLIFORM (PER 100 ML)
* FSTRP ... POND CONCENTRATION OF FECAL STREPTOCOCCUS (PER 100 ML)
* KFTC20 ... CONSTANT FACTOR
* KFTC ... RATE CONSTANT FOR DEGRADATION OF COLIFORM BACTERIA
* KFS20 ... RATE CONSTANT FOR DEGRADATION OF FECAL STREPTOCOCCUS
       KFTC=KFTC20+0.0075*(PT-20.)
       TCOLI=TCOLI*(1.-10.**(KFTC))+PTCCLI*RUNOFF/(PONVOL+DISVOL+DSCHRG)
       FCOLI=FCOLI*(1.-10.**(KFTC))+RFCOLI*RUNOFF/(PONVOL+DISVOL+DSCHRG)
       FSTRP=FSTRP*(1.-10.**(KFS20))+RFSTRP*RUNOFF/(PONVOL+DISVOL+DSCHRG)
*
* DAILY OUTPUT    (RETURN SOME TO ENGLISH UNITS)
  60   WRITE(3,301)MO,DA,YR,PT,GGHT,PLSA,AIA(PONVOL)*LTAREA*3630.,
      + LTAREA*43560.,IN(PRECIP),IR(DF(TC),0),PA(SLUDGE),JDATE
       WRITE(4,401)IR(PCOD,0),IR(PNH3,0),IR(PORGN+PNH3,0),IR(PORGN,0),
      + IR(PTOTP,0),IR(PTS,0),IR(PFDS,0),IR(PTVS,0),
      + TCOLI,FCOLI,FSTRP,JDATE
       INDFRZ=1H
       IF(FRZ0.EQ.1)INDFRZ=6HFROZEN
       IF(KP.GT.1.)INDFRZ=8HSNOWMELT
* (RUNOFF REPORT LINES ONLY FOR DAYS WITH RUNOFF)
       IF(T.NE.0)PRINT 501,MO,DA,YR,CCOD,NTOT,P,FDS,
      +   RTCOLI,RFSTRP,T,JDATE,NH3,RFCOLI,INDFRZ
       WRITE(5,BETA)  $  WRITE(5,504)  $  ENDFILE 5
       T9=T8
       T8=T7
       T7=T6
       T6=T5
       T5=T4
       T4=T3
       T3=T2
       T2=T1
       T1=T0
       FRZ1=FRZ0
       GOTO 10
*
*
*
```

APPENDIX F (continued)

```
  200  FORMAT(1X,I3,3I2,2F10.3,10X,5F10.3,10X,F4.1,I1,F10.2,F5.2)
  300  FORMAT(1H1/T15,≠POND          STAFF    POND       POND      LOT ≠,
     +   14X,≠AVG          SLUDGE≠/T5,≠DATE≠,T15,≠TEMP≠,6X,
     +   ≠GAUGE  SURFACE  VOLUME      AREA       PRECIP    TEMP       MASS≠/
     +   T14,≠(DEG C)≠,4X,
     +   ≠(FT)     (SQ FT)   (CU FT)   (SQ FT)       (IN)     (DEG F)   (LB/A)≠/)
  301  FORMAT(T3,2(I2,1H/),I2,2(3X,F6.2),1X,
     +    3E9.3E1,3X,F6. 2,3X,I3,3X,E9.3E1,T121,1H(,I4,2H ))
  400  FORMAT(1H1/2H .,T7,≠COD  NH3-N        ORG-N  PO4-P≠,
     +   29X,≠BACTERIA/100  ML≠/2H .,T5,
     +   ≠(PCOD)(PNH3)  TKN  (PORGN)(PTOTP)  PTS    PFDS   LTVS       ≠,
     +   23(1H.)/2H .,T5,5(≠(MG/L)≠),3(1X,≠(MG/L)≠),
     +   ≠      TCOLI     FCOLI      FSTRP≠/)
  401  FORMAT(2H .,T4,5I6,3I7,1X,3E9.3E1,T121,1H(,I4,2H ))
  500  FORMAT(1H1/T40,≠R U N O F F   Q U A L I T Y≠///
     +     T28,≠SOLUTION CONCENTRATIONS IN MG/L≠,
     +     T72,≠BACTERIA COUNTS PER 100 ML≠/
     +     T19,49(1H.),T72,26(1H.)/
     +     T60,≠FIXED≠,T75,≠TOTAL≠,T89,≠FECAL≠,
     +     T99,≠CONSECUTIVE≠/T8,≠DATE≠,T21,≠COD≠,
     +     T32,≠NITROGEN≠,T44,≠PHOSPHORUS≠,T57,≠DISSOLVED≠,
     +     T73,≠COLIFORMS≠,T88,≠STREPTO-≠,T101,≠DAYS OF≠/
     +     T34,≠[NH3]≠,T59,≠SOLIDS≠,T72,≠[FECAL COLI]≠,
     +     T89,≠COCCI≠,T101,≠RUNOFF≠/)
  501  FORMAT(4X,2(I2.2,1H/),I2.2,5X,4(G10.3,3X),3X,
     +     2(G10.3,4X),2X,I3.0/6X,1H[,I3.3,1H],
     +     18X,1H[,G10.3,1H],28X,1H[,G10.3,1H],18X,A10/)
  502  FORMAT(≠0--CLEAR PAGE EJECT≠)
  503  FORMAT(≠T--SET TO 8LL/IN≠)
  504  FORMAT(5(/))
       END
430008 CM STORAGE USED        1.628 SECONDS
```

APPENDIX G

DEFINITION OF TERMS AND COMPUTER PROGRAM FOR THE AMMONIA LOSS PREDICTION MODEL

```
*DROP     PREDICTION OF SPRAY DROPLET DECELERATION AND EVAPORATION
          PROGRAM DROP(INPUT=/80,OUTPUT=/137,TAPE5=INPUT,TAPE6=OUTPUT)
C       THIS PROGRAM CALCULATES TRAJECTORIES OF EVAPORATING SPRAY DROPLETS
C       PROGRAM DEVELOPED BY AGR. ENGR. DEPT, UNIV. OF MISSOURI, JANUARY 197
C       MODIFIED BY AGR. ENGR. DEPT, OREGON STATE UNIVERSITY, AUGUST 1978
C         (VERSION INCLUDES APPROXIMATION OF EVAPORATIVE NH3 LOSSES)
          REAL KE,KEI,KZ
          DIMENSION LR(400)
          DIMENSION Y(8),X(8),GA(8),PE(8),XX(4,8),H(9),ZZ1(8),ZZ2(8)
         1,ZZ3(8),IFL(7),AR(800),PAR1(8),PAR2(8),PAR3(8),PAR4(8)
          COMMON/IZ/TDBF,RH,PATM,WXYMPH,WZMPH,SPRMPH,THETXH,THETAZ,CONC,
     +      HON,PNOZ,NINT,IPNT,NK,DMAX,XMM,XMV,RINO,PHI,ZRN,WDHF,ZO,VAI,
     +      T,TIME,TIME84,SUMNL,PCTLOS,FP
          EQUIVALENCE (AXISY,Y(5)),(AXISX,Y(6))
          DATA PAR1(1),PAR1(2),PAR1(3),PAR1(4),PAR1(5),PAR1(6),PAR1(7),PAR1
         1(8)/465.0,758.26,454.95,348.3,330.0,363.3,644.95,450.0/
          DATA PAR2(1),PAR2(2),PAR2(3),PAR2(4),PAR2(5),PAR2(6),PAR2(7),PAR2
         1(8)/73.0,74.0,76.0,80.0,80.0,80.0,76.0,72.0/
          DATA PAR3(1),PAR3(2),PAR3(3),PAR3(4),PAR3(5),PAR3(6),PAR3(7),PAR3
         1(8)/.23,.16,.15,.15,.15,.15,.15,.16/
          DATA PAR4(1),PAR4(2),PAR4(3),PAR4(4),PAR4(5),PAR4(6),PAR4(7),PAR4
         1(8)/1.0,1.0,10.0,1.0,10.0,10.0,10.0,10.0/
          PI=4.*ATAN(1.)
*
*
 1111 CALL INLZ
*
*
        KOUNT=0
        TRMRK=-1.0E9
        SZMRK=-1.0E9
        IEND=0
        KEEP=1
        IFL(1)=-1
1       IFL(2)=-1
2       CALL RKFOUR(NINT,Y,X,GA,PE,XX,H,ZZ1,ZZ2,ZZ3,TIME,PNTS,KEEP,IFL)
        IF(IFL(4))3,4,5
3       CONTINUE
*
        G=386.
        H(1)=0.0001
C     INPUT DROPLET CHARACTERISTICS
        OILF=0.
        DENSO=1.935/12.0**4
C     THE FOLLOWING STATEMENTS CONTROL TERMINATION AND PRINTING
        DMIN=1.
        XMAX=50.*12.
        YMAX=50.*12.
        IHARD=0
        IOUT=2
        IPLOT=0
C     COMPUTE OTHER INITIAL CONDITIONS
        VLRN=SQRT(1.6*PNOZ/DENSO)
        CMTI=(1.0E-6)*39.37
        WDH=WDHF*12.
        DMAXI=DMAX*CMTI
        DFIXI=(OILF**0.33333)*DMAXI
        DMINI=DMIN*CMTI
        BASE=12.0*CMTI
        TKEL=((TDBF-32.)/1.8)+273.
        TDBR=TDBF+459.4
        DV=(5.28E-6*TKEL**1.88)/(2.54*2.54)
        DENSA=PATM/(G*539.6*TDBR)
        VISCA=(1.0E-7/144.)*EXP(1.258+0.001262*TDBF)
        VISCAK=VISCA/DENSA
        SNO=DV/VISCAK
        PHIR=PHI*PI/180.
        WZ=WZMPH*5280./300.
        SPEED=SPRMPH*5280./300.
```

Reproduced from best available copy.

```
      EPS=1.0E-40
C  THE FOLLOWING CARDS SIMULATE THE EFFECT OF TURBULENCE
      USTAR=(WXYMPH*5280./300.)*0.4/(ALOG(WDH/ZO)-4.5*(-RINO/(1.-5.*RINO
     1)))
      WZ=-1.32*USTAR**3*ABS(RINO)**1.5/(0.064*G*ZRN*(1.-18.*RINO)**.75)
C  COMPUTE PRESSURE RATIO FROM BROOKERS MODEL
      A1=54.6329
      A2=12301.688
      A3=5.16923
      A4=1075.8965
      A5=-0.56983
      PS=2.71828**(A1-A2/TDBR-A3*ALOG(TDBR))
      PV=PS*RH
      PXP=PS
      TXP=TDBR
*
      DO 205 J=1,10
      BB=0.2405*(PXP-PATM)/(0.62194*(A4+A5*(TXP-491.69)))
      BP=PXP*(A2/TXP**2-A3/TXP)
      TX=(BP*TXP -PXP+PV-BB*TDBR)/(BP-BB)
      PX=2.71828**(A1-A2/TX-A3*ALOG(TX))
      IF(ABS(PXP-PX).LE.0.001.AND.ABS(TXP-TX).LE.0.1) GO TO 209
      PXP=PX
205    TXP=TX
*
209   PSWB=PX
      PAIR=PATM-PV
      RATIO=(PSWB-PV)/PAIR
      CON1=-2.0*XMV/XMM*DV*DENSA/DENSD*RATIO
      CON2=0.6*SNO**0.333333
      Y(1)=VLRN*SIN(THETAZ*PI/180.)*COS(THETXH*PI/180.)
      Y(3)=SPEED+VLRN*SIN(THETAZ*PI/180.)*SIN(THETXH*PI/180.)
      Y(5)=VLRN*COS(THETAZ*PI/180.)
      Y(8)=DMAXI
      NK=NK+1
      IF(NK.EQ.1)WRITE(6,80)DENSD,XMV,OILF,DENSA,VISCA,TDBF,RH,DV,SNO
     1,RATIO,WXYMPH,WDHF,PHI
      IF(NK.EQ.1)WRITE(6,81) ZRN,RINO,USTAR,WZ,SPRMPH,THETAZ,THETXH,HON,
     1 VLRN,VAI
80    FORMAT(1H1/11X,≠SIMULATION OF SPRAY DROPLET TRAJECTORIES≠/
     1 5X,≠PROGRAM BY AGR. ENGR. DEPT., UNIV. OF MISSOURI,COLUMBIA,MO.≠/
     1/≠ ***SPRAY LIQUID PROPERTIES≠/
     2≠ DENSITY=≠,E12.4,≠ LB-SEC2/IN4≠/
     3≠ MOLECULAR WEIGHT=≠,F5.1/
     4≠ OIL FRACTION=≠,F5.2,≠ (DECIMAL)≠/
     5/≠ ***AIR PROPERTIES≠/
     6≠ DENSITY=≠,E12.4,≠ LB-SEC2/IN4≠/
     7≠ DYNAMIC VISCOSITY=≠,E12.4,≠ LB-SEC/IN2≠/
     8≠ DRY BULB TEMP=≠,F7.1,≠ DEG F≠/
     9≠ REL HUMIDITY=≠,F5.2,≠ (DECIMAL)≠/
     A/≠ ***AIR-LIQUID PROPERTIES≠/
     1≠ DIFFUSIVITY=≠,E12.4,≠ IN2/SEC≠/
     2≠ SCHMIDT NO.=≠,F6.3,≠ (DIMENSIONLESS)≠/
     3≠ VAPOR PRESSURE RATIO=≠,E12.4/
     4/≠ ***APPLICATION PARAMETERS≠/
     5≠ HORIZONTAL WIND SPEED=≠,F6.1,≠ MPH AT≠,F5.1,≠ FT AND≠,F6.0,
     6≠ DEG CW FROM X-AXIS≠)
81    FORMAT(/2X,≠RICHARDSON NO (AT≠,F6.2,≠ INCHES)=≠,F7.3/
     7≠ USTAR=≠,E12.4,≠ IN/SEC≠/
     8≠ VERTICAL AIRSPEED=≠,E12.4,≠ IN/SEC≠/
     9≠ SPRAYER SPEED=≠,F5.1,≠ MPH≠/
     A≠ LAUNCH ANGLES=≠,F6.1,≠ DEG FROM Z-AXIS AND≠,F6.1,≠ HORIZ. DEG CW
     B FROM X-AXIS≠/
     1≠ LAUNCH HEIGHT=≠,F6.1,≠ INCHES≠/
     2≠ LAUNCH SPEED REL. TO NOZZLE=≠,E12.4,≠ IN/SEC≠/
     3≠ INDUCED AIR=≠,F3.0,≠ (1=YES,0=NO)≠)
C  THE FOLLOWING SECTION IS FOR CHANGING PARAMETERS
      WRITE(6,43)TDBF,RH,WXYMPH
43    FORMAT(/≠ TEMP=≠,F6.2,≠ DEG F,RH=≠,F4.2,≠ WIND SPEED≠,F4.1,≠ MPH≠)
      IF(IOUT.NE.0)WRITE(6,82)
82    FORMAT(/2X,≠TIME,SEC   XDOT,IN/SEC  YDOT,IN/SEC ZDOT,IN/SEC  X,INC
     1HES    Y,INCHES     Z,INCHES     D,MICRONS    REYN. NO.    -NH3,MOL
     2 -NH3,%LEFT≠)
4      CONTINUE
*
C
C  INTEGRATOR I/O IDENT--X(1)=XDD,Y(1)=X(2)=XD,Y(2)=X,X(3)=YDD,
C  Y(3)=X(4)=YD,Y(4)=Y,X(5)=ZDD,Y(5)=X(6)=ZD,Y(6)=Z,X(7)=VDROP,
C  Y(7)=DIST,X(8)=DDOT,Y(8)=DIAM
C
```

```
      VIA=VLRN*((BASE/Y(8))**0.2)*EXP(-((Y(7)/2.0)**0.67))*VAI
      VDROP=SQRT(Y(1)*Y(1)+Y(3)*Y(3)+Y(5)*Y(5))
      ARG=(HON-Y(6))/ZO
      WXY=0.
      IF(ARG.GT.1.) WXY=2.5*USTAR*(ALOG(ARG)+4.5*RINC/(1.-5.*RINO))
      WX=WXY*COS(PHIR)
      WY=WXY*SIN(PHIR)
      WX1=WX+VIA*Y(1)/VDROP
      WY1=WY+VIA*Y(3)/VDROP
      WZ1=WZ+VIA*Y(5)/VDROP
      VREL=SQRT((WX1-Y(1))**2+(WY1-Y(3))**2+(WZ1-Y(5))**2)
      REYN=VREL*Y(8)/VISCAK
      CD=24./(REYN+EPS)
      IF(REYN.GE.0.5)  CD=(26.38/REYN**0.845)+0.49
      DRAG=PI/8.*DENSA*CD*VREL*VREL*Y(8)*Y(8)
      DDOT=CON1/Y(8)*(2.+CON2*REYN**0.5)
      IF(Y(8).LE.DFIXI)  DDOT=0.
      DPEF=DENSD*PI/2.*DDOT*Y(8)*Y(8)*VREL+DRAG
      XMASS=PI/6.*Y(8)**3*DENSD
      X(1)=DPEF*(WX1-Y(1))/(XMASS*VREL)
      X(2)=Y(1)
      X(3)=DPEF*(WY1-Y(3))/(XMASS*VREL)
      X(4)=Y(3)
      X(5)=(DPEF*(WZ1-Y(5))/(XMASS*VREL))+G
      X(6)=Y(5)
      X(7)=VDROP
      X(8)=DDOT
      GO TO 2
 5    CONTINUE
*
      ZMAX=HON-ZO-0.25
      IF(Y(2).GE.XMAX.OR.Y(4).GE.YMAX)  IEND=1
      IF(REYN.GT.0.5.AND.IHARD.NE.0)  IEND=0
      IF(Y(8).LE.DMINI.OR.Y(6).GE.ZMAX)  IEND=1
      DELTR=Y(7)-TRMRK
      DELSZ=ABS(Y(8)-SZMRK)
      TRMIN=0.1*Y(7)
      SZMIN=CMTI
      IF(TRMIN.LT.0.5)  TRMIN=0.5
      IF(TRMIN.GT.20.)  TRMIN=20.
      IF(DELTR.LT.TRMIN.AND.DELSZ.LT.SZMIN.AND.IEND.NE.1) GO TO 16
      KOUNT=KOUNT+1
      IF(KOUNT.LT.IOUT.AND.KOUNT.NE.1.AND.IEND.NE.1) GO TO 16
      DOUT=Y(8)/CMTI
      IF(IOUT.EQ.0)GOTO 245
      CALL NH3LOS(FP,TKEL,PATM*6891.156,REYN,DMAX/1.E6,CONC,
     +  PI,TIME,TIME04,SUMNL,PCTLOS)
      WRITE(6,32)TIME,Y(1),Y(3),Y(5),Y(2),Y(4),Y(6),DOUT,REYN,
     +  SUMNL,PCTLOS
  245 TRMRK=Y(7)
      SZMRK=Y(8)
      KOUNT=1
 32   FORMAT(1X,11E12.4)
 16   CONTINUE
*
      NPL=1
      IF(IPLOT.NE.0)NPL=IPLOT*(KOUNT/IPLOT)-KOUNT
      IF(IEND.EQ.0)  GO TO 1
      IF(REYN.GT.0.5.OR.VIA.GE.1.0) GO TO 60
      XNU=2.+CON2*REYN**0.5
      DELT=0.1
      KEI=ABS(DDOT*Y(8))
      KE=KEI
      KZ=G*(DENSD-DENSA)/(18.*VISCA)
      TO=TIME
      T=TO
      IENO=0
      WRITE(6,65)
 65   FORMAT(/' BEGIN SMALL REYNOLDS NUMBER SIMULATION')
      ZI=Y(6)
      YDIST=Y(4)
      XDIST=Y(2)
      XMARK=Y(2)
      YMARK=Y(4)
      DMARK=Y(8)/CMTI
      DIAO=Y(8)
      SIF=0.5
 47   T=T+DELT
      DIA=0.
      IF((DIAO*DIAO-2.*KE*(T-TO)).GT.0.)DIA=SQRT(DIAC*DIAO-2.*KE*(T-TO))
      ZDOT=KZ*DIA*DIA+WZ
      ZDIST=ZI+WZ*(T-TO)+KZ*(DIAO*DIAO+2.*KE*TO)*(T-TO)-KE*(T*T-TO*TO)
      DOUT=DIA/CMTI
      WXY=0.
      IF((HON-ZDIST).GT.ZO)
```

APPENDIX G (continued)

```
       1 WXY=2.5*USTAR*(ALOG((HON-ZDIST)/Z0)+4.5*RIND/(1.-5.*RIND))
         XDOT=WXY*COS(PHIR)
         YDOT=WXY*SIN(PHIR)
         REYN=DIA/VISCAK*ABS(ZDOT-WZ)
         KE=KEI/XNU*(2.+C CN2*REYN**0.5)
         XDIST=XDIST+XDOT*DELT*S1F
         YDIST=YDIST+YDOT*DELT*S1F
         S1F=1.0
         IF(ZDIST.GE.HON.OR.DIA.LE.0.0.OR.T.GE.120.) IEND=1
         IF((T-TO-DELT).LE.(1.1*DELT)) GO TO 45
         IF((2.*KE*(T+DELT-TO)).GE.(DIAO*DIAO)) GO TO 45
         DELTX=XDIST-XMARK
         DELTY=YDIST-YMARK
         DELTD=ABS(DOUT-DMARK)
         TRG=600.
         IF(DELTX.LT.TRG.AND.DELTY.LT.TRG.AND.DELTD.LT.20.0.AND.IEND.EQ.0)
       1 GO TO 46
         XMARK=XDIST
         YMARK=YDIST
         DMARK=DOUT
   45    IF(IOUT.EQ.0)GOTO 2455
         CALL NH3LOS(FP,TKEL,PATM*6891.156,REYN,DMAX/1.E6,CONC,
       +   PI,T,TIME84,SUMNL,PCTLOS)
         WRITE(6,32)T,XDOT,YDOT,ZDOT,XDIST,YDIST,ZDIST,DOUT,REYN,
       +   SUMNL,PCTLOS
   2455  IF(IEND.EQ.1) GO TO 60
   *
   46    CONTINUE
   *
         GO TO 47
   60    CONTINUE
   *
   *
   *
         PRINT*,≠ ≠
         PRINT*,≠ ≠
         PRINT*,≠ ≠
         PRINT*,≠       TYPE  <RETURN> TO STOP      ≠
         READ 5555,MORE
    5555 FORMAT(A1)
         IF(EOF(5LINPUT).NE.0)STOP
         GOTO 1111
         END
41000B CM STORAGE USED         1.363 SECONDS
```

APPENDIX G (continued)

```
      SURROUTINE RKFOUR(N,Y,X,GAIN,PEAK,XX,H,C1,C2,C3,TIME,PNTS,KEEP,FL)
      DIMENSION Y(N),X(N),GAIN(N),PEAK(N),XX(4,N),H(9),C1(N),C2(N),
     1C3(N),A(8)
      INTEGER FL(7)
      DATA A(1)/0.1/,A(2)/0.0/,A(3)/1.0E8/,A(4)/1.414214/,A(5)/1.0E-4/
      DATA A(6)/1.0E-2/,A(7)/0.0/,A(8)/3.0/
      IF(FL(1))1,3,20
*
    1 DO 2 I=1,N
      Y(I)=0.0
      PEAK(I)=0.0
    2 GAIN(I)=1.0
      TIME=0.0
      PNTS=0.0
      FL(4)=-1
      FL(5)=1
      FL(1)=0
*
      DO 9 I=1,8
    9 H(I)=A(I)
      RETURN
    3 Q=H(1)
      FL(4)=1
      FL(7)=H(8)
    4 H(1)=Q
      FL(3)=0
*
      DO 5 I=1,N
      C2(I)=GAIN(I)*Q
      C1(I)=0.5*C2(I)
    5 C3(I)=C2(I)/6.
      IF(FL(1))6,6,10
   10 IF(FL(2))31,33,33
    6 FL(1)=1
    7 PNTS=PNTS+1.
*
      DO 8 I=1,N
      XX(3,I)=Y(I)
    8 XX(4,I)=X(I)
      FL(4)=1
      H(9)=TIME
      RETURN
   20 IF(FL(3))25,30,25
   25 IF(FL(2)-3)26,60,60
   26 IF(FL(3))21,30,22
   21 Q=H(1)/H(4)
      IF(Q-H(2))23,4,4
   23 Q=H(2)
      IF(Q-H(1))4,30,4
   22 Q=H(1)*H(4)
      IF(Q-H(3))4,4,24
   24 Q=H(3)
      IF(Q-H(1))4,30,4
   30 FL(5)=0
      IF(FL(2))31,40,45
   31 FL(6)=KEEP
      KEEP=0
*
      DO 32 I=1,N
      XX(1,I)=XX(3,I)
   32 XX(2,I)=XX(4,I)
   33 FL(2)=0
      TIME=H(9)+0.5*H(1)
*
      DO 34 I=1,N
   34 Y(I)=XX(1,I)+C1(I)*XX(2,I)
   35 KEEP=0
   36 FL(4)=0
      RETURN
   40 FL(2)=1
*
      DO 41 I=1,N
      XX(3,I)=X(I)
   41 Y(I)=XX(1,I)+C1(I)*X(I)
      GO TO 35
   45 IF(FL(2)-2)46,48,60
   46 FL(2)=2
      TIME=H(9)+H(1)
*
```

APPENDIX G (continued)

```
      DO 47 I=1,N
      XX(4,I)=X(I)
   47 Y(I)=XX(1,I)+C2(I)*X(I)
      GO TO 35
   48 FL(2)=3
      IF(H(7))49,52,52
   49 KEEP=FL(6)
*
   50 DO 51 I=1,N
   51 Y(I)=XX(1,I)+C3(I)*(XX(2,I)+X(I)+2.*(XX(3,I)+XX(4,I)))
      GO TO 36
   52 ERR=0.0
*
      DO 56 I=1,N
      ESTERR=C2(I)*ABS(XX(2,I)+X(I)-2.*XX(4,I))
      IF(PEAK(I))53,53,54
   54 ESTERR=ESTERR/PEAK(I)
   53 IF(ERR-ESTERR)55,56,56
   55 ERR=ESTERR
   56 CONTINUE
*
      IF(ERR-H(6))57,57,66
   57 IF(ERR-H(5))58,59,59
   58 FL(7)=FL(7)-1
      IF(FL(7))65,65,49
   65 FL(3)=1
      GO TO 49
   59 FL(7)=H(8)
      GO TO 49
   66 FL(7)=H(8)
      GO TO 21
   60 IF(H(7))7,61,61
*
   61 DO 63 I=1,N
      ERR=ABS(Y(I))
      IF(ERR-PEAK(I))63,63,62
   62 PEAK(I)=ERR
   63 CONTINUE
*
      GO TO 7
      END
41000B CM STORAGE USED          .387 SECONDS
```

APPENDIX G (continued)

```
            SUBROUTINE NH3LOS
           +   (FP,T,P,R,DP,CAL,PI,TNOW,TB4,SUMNL,PCTLOS)
            REAL KC,KD,N1,N2,NL,N11
      *
      ***** NAMELIST/BBB/T,P,R,DP,DAB,S,KC,KD,CAS,CAL,WA,
      *****+   N1,N11,N2,NL,SUMNL,TB4,TNOW,PH,FP
      ***** PRINT*,≠ ≠ $ PRINT*,≠ ≠
      ***** PRINT BBB
            IF(TNOW.EQ.0.)RETURN
      *
            IF(TB4.EQ.0.0)SUMNL=0.0
            DAB=4.447E-4*T**1.5/P
            S=11.93/SQRT(T)
            KC=DAB/DP*(2.0+0.552*SQRT(R)*S**(1./3.))
            KD=2.31E-5*T-6.12E-3
            CAS=KD*CAL
            WA=PI*DP*DP*KC*CAS
            NL=WA*(TNOW-TB4)*FP
            N1=CAL*PI*DP**3/6.0
            IF(TB4.EQ.0.0)N11=N1
            N2=N1-NL
      ***** PRINT BBB
            CAL=6.0*N2/(PI*DP**3)
            SUMNL=SUMNL+NL
            PCTLOS=0.0
            IF(N11.NE.0.0.AND.TNOW.GT.0.)PCTLOS=(N11-SUMNL)/N11*100.
            TB4=TNOW
      ***** PRINT BBB
            RETURN
            END
41000B CM STORAGE USED          .096 SECONDS
```

APPENDIX G (continued)

```
      SUBROUTINE INLZ
*** INITIAL VALUE ROUTINE ***
      COMMON/IZ/TDBF,RH,PATM,WXYMPH,WZMPH,SPRMPH,THETXH,THETAZ,CONC,
     +  HON,PNOZ,NINT,IPNT,NK,DMAX,XMM,XMV,RINO,PHI,ZRN,WDHF,ZO,VAI,
     +  T,TIME,TIME84,SUMNL,PCTLOS,FP
      NAMELIST/INL/TDBF,RH,PATM,WXYMPH,WZMPH,SPRMPH,THETXH,THETAZ,
     +  HCN,PNOZ,DMAX,CONC,PH
*
      PRINT 100  $  TDBF=50. $ RH=.3 $ PATM=14.7 $ WXYMPH=5. $ DMAX=200.
      CONC=WZMPH=THETXH=T=TIME=TIME84=SUMNL=PCTLOS=0.
      HON=24. $ PNOZ=40. $ SPRMPH=5. $ IPNT=NK=0 $ NINT=8 $ PH=7.
      THETAZ=90.  $  PRINT INL  $  PRINT 100
*
      PRINT*,≠ IF ANY OF THE ABOVE VALUES ARE ACCEPTABLE.≠
      PRINT*,≠ PRESS <RETURN> KEY ONLY≠  $  PRINT*,≠ ≠
C   INPUT ATMOSPHERIC CONDITIONS
      XMM=29.  $  XMV=18.
      PRINT*,≠ ENTER TEMPERATURE (DEG F)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)TDBF=XXIN
      PRINT*,≠ ENTER RELATIVE HUMIDITY (%)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)RH=XXIN
      IF(RH.GT.1.)RH=RH/100.
      PRINT*,≠ ENTER ATMOSPHERIC PRESSURE (PSI)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)PATM=XXIN
      PRINT*,≠ ENTER WIND SPEED COMPONENTS (MPH)≠
      PRINT*,≠    WXY-MPH≠  $  READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)WXYMPH=XXIN
      PRINT*,≠    WZ-MPH≠  $  READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)WZMPH=XXIN
      RINO=PHI=0. $ ZRN=39.37 $ WDHF=6.
C   INPUT LAUNCH CONDITIONS
      ZO=0.7/2.54
      VAI=1
      PRINT*,≠ ENTER INITIAL SPRAY VELCCITY (MPH)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)SPRMPH=XXIN
      PRINT*,≠ ENTER COMPONENTS OF SPRAY DIRECTION≠
      PRINT*,≠    THETXH≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)THETXH=XXIN
      PRINT*,≠    THETAZ≠  $  READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)THETAZ=XXIN
      PRINT*,≠ ENTER NOZZLE HEIGHT (INCHES)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)HON=XXIN
      PRINT*,≠ ENTER NOZZLE PRESSURE (PSI)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)PNOZ=XXIN
      PRINT*,≠ ENTER MAXIMUM DROPLET DIAMETER (MM)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0.AND.XXIN.GT.2.E-3)DMAX=XXIN*1000.
      PRINT*,≠ ENTER INITIAL NH3 CONCENTRATION (MOL/M3)≠
      READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)CONC=XXIN
      PRINT*,≠ ENTER PH≠  $  READ*,XXIN
      IF(EOF(5LINPUT).EQ.0)PH=XXIN
      FP=1./(10.**(9.26-PH)+1.)
*
      PRINT 100  $  PRINT INL  $  PRINT 101
*
      RETURN
  100 FORMAT(/////1HS)
  101 FORMAT(/////1HT)
      END
410009 CM STORAGE USED         .311 SECONDS
```

APPENDIX H

ENGLISH TO SI UNIT CONVERSIONS

English Unit	Equivalent SI Unit
mi	1.609 km
ft	0.304 m
in	2.54 cm
acre	0.405 ha
ft^2	0.0929 m^2
ft^3	0.0283 m^3
lb	0.454 kg
$^{\circ}$F	0.555 $^{\circ}$C

$^{\circ}C = (^{\circ}F - 32)\ 0.555$